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THE RADIO MANUAL

by

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Commissioner
Federal Communications Commission

AND

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CHAPTER ON TELEVISION BY THOMAS T. GOLDSMITH, JR.
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PREFACE

The fourth edition of The Radio Manual, like previous editions, is designed to serve as a textbook and reference for those entering the profession of electronics and telecommunications. In addition, it is designed to meet the needs of the engineer and operator already engaged in the profession as they encounter the many systems of communication employed in various stations and services. Moreover, the text provides a comprehensive reference for colleges, schools, and public libraries, as well as for students preparing for radio operator license examinations.

The chapters covering electrical and radio theory have been thoroughly revised and new material in keeping with the progress made in the art and industry has been added.

As in former editions, the policy of furnishing technical data covering representative commercial radio equipment directly from the instruction books and other literature of the manufacturer has been retained in this edition. An attempt has been made to include descriptions of the equipment of as many different manufacturers as possible. As an example, Chapter 11 describes a considerable number of different commercial FM transmitting equipments, all of which meet the Federal Communications Commission Standards of Good Engineering Practice, but accomplish FM transmission in a different manner.

Because of space limitations, it obviously has not been possible to describe the equipments of all manufacturers. However, it should not be assumed that the equipments chosen for description are superior to similar equipments produced by other manufacturers, nor should it be assumed that their selection for description in this text constitutes preference on the part of the Federal Communications Commission with which agency one author is associated. The decisions as to the types of apparatus to be described are solely those of the authors.

The authors and publisher have been confronted with the usual problems that are encountered in composing the text of a book which is associated with a dynamic art and industry that is progressing as rapidly as that of telecommunications and electronics. The television chapter is a good example. After this chapter had been completed by Dr. Goldsmith, the color issue became dominant and, consequently, a major revision of this chapter was undertaken in order to include brief descriptions of the three systems of color television that are currently under consideration.

Experience has shown that when the page proof of a book has been completed, the author is always tempted to change the original material, or add new material, to describe the very latest developments in the subject under discussion. Authors of technical books are always vulnerable in this respect and we are no exception. As in all things, however, there must be a degree of finality and we offer this edition with the hope that errors and omissions will be brought to our attention.

In order to enhance the value of the text, new chapters on Radio Wave Propogation and Antennas have been added. There has also been added a chapter covering Radar and Loran as applied to marine navigation. As in former editions, the text concludes with the latest rules and regulations, laws and treaties as they pertain to the daily tasks of radio engineers and operators. This material should prove useful to students preparing to take examinations for the various classes of radio operators licenses.

Sincere appreciation is expressed to the many manufacturers and individuals who contributed to this edition of *The Radio Manual* and particularly to Dr. Thomas Goldsmith for his planning and labors in producing the chapter on television. Appreciation is also expressed to Robert S. Kruse and William R. Foley for the preparation of material in chapters 4, 5, and 6 which has been carried over into this edition from the third edition.

G. E. S.
R. B. M.

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CHAPTER 1

ELEMENTARY ELECTRICITY AND MAGNETISM

Among laymen, one often hears an expression such as "No one knows what electricity is," and the statement often continues "scientists know only how to use it." On the contrary, scientists and physicists are able to explain in great detail the nature and composition of electricity as well as its relation to matter. In fact, more is known about electricity than most other phenomena of nature, and that knowledge has served as a key to unlock doors leading to further knowledge in other fields which heretofore has completely eluded us.

1–1. The Electron Theory—All matter, whether in the solid, liquid, or gaseous state, is regarded as being composed of minute bodies called atoms. Until late in the nineteenth century, the atom was considered to be the ultimate and indivisible particle of matter. At that time, a series of ingenious experiments showed that the atom was by no means the smallest particle but was actually a complex structure in itself, being made up of even smaller particles. The atom, it was found, is made up of a positively charged nucleus about which revolve a number of infinitesimally small negative particles, in much the same manner that the planets of our solar system revolve around the sun. These tiny negative particles, which form the very basis of our present conception of electricity, are known as *electrons.*

As knowledge of nuclear physics advanced, it was learned that several other elementary particles in addition to the electron are involved in the composition of the atom. Two of these particles, the proton and positron, contain a positive charge, while two others, the neutron and neutrino, are uncharged. A group of these particles bound tightly together form the positively charged nucleus of the atom.

The electrical charge displayed by an atom, under normal conditions, is zero, that is, the positive charge of the nucleus is cancelled by the equal negative charge of the electrons revolving around it. The atom is therefore normally in electrical equilibrium.

Each of the more than ninety elements known to chemistry may be considered as being made up of different combinations of the above-mentioned fundamental elements of matter. For example, the hydrogen atom is made up of a single proton as a nucleus about which rotates a single electron. This is the simplest atomic structure. A helium atom is slightly more complex, being composed of a nucleus containing two protons and two neutrons about which revolve two electrons. Hence, it can be seen that these fundamental particles of matter serve as building blocks from which are formed the most complex atomic structures, these atomic structures in turn forming all the familiar matter of nature.

1–1a. The Electron—In electronic and electrical work, the electron is of major interest because the electron is the fundamental unit of electricity, that is, the movement of an electron in a conductor constitutes a flow of electricity.

All electrons, whether from an atom of iron, lead, mercury, potassium, or any of the other known elements, are identical. An electron removed from an atom of iron is precisely the same as an electron removed from an atom of gas such as hydrogen or helium.

The electron is an exceedingly minute body, so small that the most powerful microscope could not make visible hundreds of thousands of them grouped together. Nevertheless, considerable knowledge of the physical and electrical characteristics of the electron has been gained. The exact shape of the electron is not known, but its radius has been found to be approximately 2×10^{-13} cm (centimeter). The mass of the electron has been found to be approximately 0.91×10^{-27} g (gram). Most important of the characteristics of the electron, as will become evident subsequently, is its electrical charge which has been found to be approximately 1.6×10^{-19} coulomb.

The electrons of an atom are grouped around the nucleus in planetary orbits. They are held in place by a balance between two forces; one the centrifugal force from rotation which tends to force them away from the nucleus; the other the attractive force of the positive nucleus which tends to draw them to it.

In relatively complex atoms, where a large number of electrons are involved in the atomic structure, the electrons in the outermost orbits are not strongly bound to the nucleus and, by the application of a suitable force, a small number of these loosely bound electrons may be removed from the atom. When this is done, the electron is known as an unbound electron. The removal of a few electrons in this manner will cause no change in the atom's composition, that is, the reduced number of electrons will not cause it to become a different element. To accomplish this, the structure of the nucleus would have to be changed. When electrons have been removed, the atom will exhibit a slight positive charge and will attract to it another unbound electron which will combine and restore the atom to its original state.

The recombining of an electron with a positively charged atom does not occur instantly because the electron does not drop into the place of the missing electron and stop suddenly. Instead, it oscillates before settling down, and in most cases the frequency of its oscillation produces a wave motion of such a frequency that it is visible to the eye. These wave motions are called light. The rate of oscillation depends on the element; therefore, under these circumstances, atoms of different elements radiate different colors of light. The radiated color is characteristic of that substance, and one of our most useful methods of identifying substances depends on such characteristic radiation as the intense orange red of neon when excited by an electric current in the familiar advertising signs.

1–2. Static Electricity—A body in which the atoms are in electrical equilibrium, that is, the negative charge of the electrons is equal to the positive charge of the nucleus, will be neither negatively nor positively electrified. This is the normal condition of all bodies. In other words, they are uncharged. This electrical balance can often be upset by mechanical means, such as friction. Thus it is possible for a body to acquire a surplus of electrons in which case it is said to have a negative charge; or it can acquire a deficiency of electrons in which case it is said to be positively charged.

Three general statements can now be made:

1. A body having an excess of electrons is said to be negatively electrified or charged.
2. A body having a deficiency of electrons is said to be positively electrified or charged.
3. A body in which the negative charge of the electrons and the positive charge of the nucleus are equal is said to be uncharged.

1–2a. Charging a Body by Friction—A very simple example of frictional electricity can be demonstrated by the familiar experiment of tearing a sheet of paper into small bits and picking them up by means of a hard rubber rod which has been rubbed with a woolen cloth or fur (Figure 1–1). If the rod is clean, the day dry (and preferably cold), and the paper thoroughly dried by heating, it will be found that bits of paper will jump to the rod with surprising alacrity. The friction between the rod and wool produces a charge on each. Electrons are removed from the wool by friction and remain on the rubber rod. As already stated, however, the electrons added to the rod do not change its atomic structure, neither is there any change made in the atomic composition of the wool by removing electrons from it. Nevertheless, from an electrical standpoint the rod now has a surplus of electrons and is therefore negatively charged, while the wool, having lost electrons, has less than its normal number and is therefore positively charged.

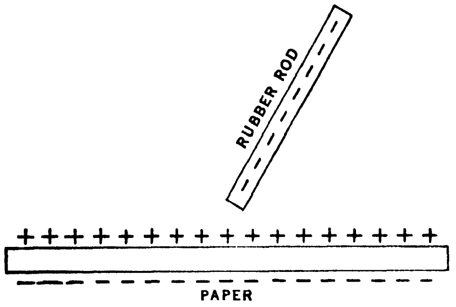


FIG. 1–1. Under the influence of the negatively charged rubber rod, electrons in the paper move to the under side of the paper.

1–2b. Relation of Charged Bodies—When the negatively charged rubber rod is brought near the bits of paper, the paper is attracted because of the difference of polarity which exists between the paper and rod. In this particular case the rubber rod bears a negative charge while the bits of paper, although uncharged, represent a positive charge with respect to the rod. Attraction between the paper and rod results.

Whenever the charges on two bodies are not equal, it is natural for shifts and readjustments to occur until a balanced condition is attained. The space surrounding the charged rod and paper is subjected to a strain enabling it to act on the paper with a force which in this case is attractive, as manifested by the small bits of paper jumping to the rod. The moment they touch the rod, the charges on each body become equalized and the attractive force disappears.

Another simple experiment can be performed with a ball of pith cut from a corn stem, and a glass rod. If the glass rod is rubbed vigorously with a piece of silk and then brought close to the pith ball, it will be found that the pith ball is attracted by the glass rod. Allow the glass rod to touch the pith ball. The ball has now become charged with electricity of the same polarity as that of the rod by the contact. It will now be noted that the rod repels the pith ball. The condition now exists where like charges repel.

From these experiments the following statements can be made.

1. Unlike charges attract. (Positive and negative charges attract each other.)
2. Like charges repel. (A negative charge repels a negative charge, likewise a positive charge repels a positive charge.)
3. Whenever a charged body is acted upon by another charged body so as to produce a force, either attractive or repulsive, the space surrounding the charged body is subject to a strain or stress. The space in which this stress occurs is called the electric field. It is sometimes called an electrostatic field.

The electric field extends in all directions from the body, the strength of the field decreasing with distance.

1–2c. Induced Charges—Consider the case of the uncharged pith ball. Let it be represented in its uncharged condition by Figure 1–2. When the charged glass rod was brought near the pith ball the negative electrons on the rod, as indicated by *B* of Figure 1–3, repelled the electrons on the side of the pith ball nearest the rod giving that side a deficit of electrons and a positive charge, as indicated by the small circle *A*. The other side, to which the electrons rushed, has a negative charge. Removing the glass rod allows the electrons to flow back into their proper place, thus discharging the body. The charge produced on the pith ball is called an induced charge.

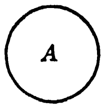


FIG. 1–2. Uncharged body.

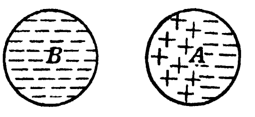


FIG. 1–3. Body A charged by electrostatic induction from charged body *B*.

The arrangement shown in Figure 1–4 will permit that body to hold more than its ordinary amount of electrons. The lines represent two conductors and the space between the lines a nonconductor. If the conductors are charged, it will be seen that they attract and bind each other and hence the conductors are able to hold a greater number of electrons than they could hold if they were not near each other.

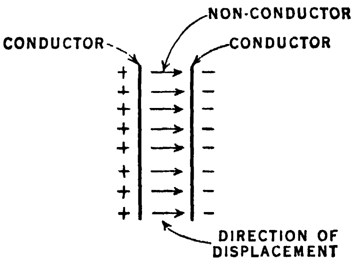


FIG. 1–4. A charged condenser

It is a general rule that a negatively charged conductor can hold more electrons if there is another conductor nearby which is charged positively at the same time. Such an arrangement of two oppositely charged conductors is called a condenser, because it permits us to concentrate, or condense a large amount of electricity on each of the two conductors. Familiar forms of condensers consist of copper or tinfoil separated by mica insulation. An equally familiar form uses air insulation and makes one plate (or set of plates) movable, so as to vary the capacitance, which is the term used to designate the ability of the condenser to hold electricity and which term has in recent years caused the condenser also to be called a capacitor. Such a condenser illustrates the point that the capacitance increases as the two conductors approach each other.

1–2d. Potential—When we speak of electric potential, we mean electrical pressure. When electrons are crowded upon a conductor, its potential rises in just exactly the same manner that the pressure in an automobile tire rises when air is crowded into it. It will be seen later that just as we can produce air pressure by rotating centrifugal pumps or by ordinary plunger pumps, so also we can produce electrical pressures by a variety of means, including batteries and generators. We have already seen how a small electrical pressure can be created by rubbing a glass rod with a silk cloth and how this pressure tends to drive electricity from one point to another so forcibly as to carry light substances with it. We will see later how the pressures created by batteries and generators will cause large currents of electricity to flow and thereby to operate all the machinery of radio transmission and reception.

1–2e. Electrons and Difference of Potential—Consider a pair of charged bodies as shown in the top portion of Figure 1–5 as *A* and *B*. *A* has an excess of electrons; thus it has a force trying to discharge electrons—it has a negative potential. *B* has a deficit of electrons, thus it has a force trying to attract electrons—it has a positive potential. If given a path, electrons would flow from *A* to *B*. Consequently the flow of electrons would constitute a flow of electric current, as electrons really are the current. The number of electrons flowing from *A* to *B* would depend upon the difference of potential between *A* and *B*. The electrons would continue to flow until there was no longer a difference of potential, that is, *A* and *B* would then have the same number of electrons.

Consider the pair *C* and *D*. Both have a negative potential, but *C* has a larger negative potential than *D* since it has relatively more electrons than *D*. Hence, there is a difference of potential equal to potential *C* minus potential *D*. If given a path, the electrons would flow from *C* to *D* and the movement of electrons would constitute a flow of current from *C* to *D*.

1–2f. Lightning, a Movement of Electrons—When a cloud and the earth are oppositely charged, there is a possibility of a lightning discharge occasioned by the readjustment of electrons in order to restore the cloud to an uncharged condition. As the charges on earth and cloud are increased, or as the distance between them becomes less, a potential sufficiently high to permit the electrons to discharge from one body to the other (the actual direction depending on the polarity of the charges on the earth and cloud) is reached. In their passage, the electrons collide with air molecules and, as a result of these collisions, electrons are often knocked out of the air molecules. A molecule which has thus lost an electron displays a positive charge and is known as an ***ion***. The removed electron joins the other electrons in their flight while the ion, because of its positive charge, proceeds in the opposite direction. With electrons moving in one direction and ions in the opposite direction many other collisions

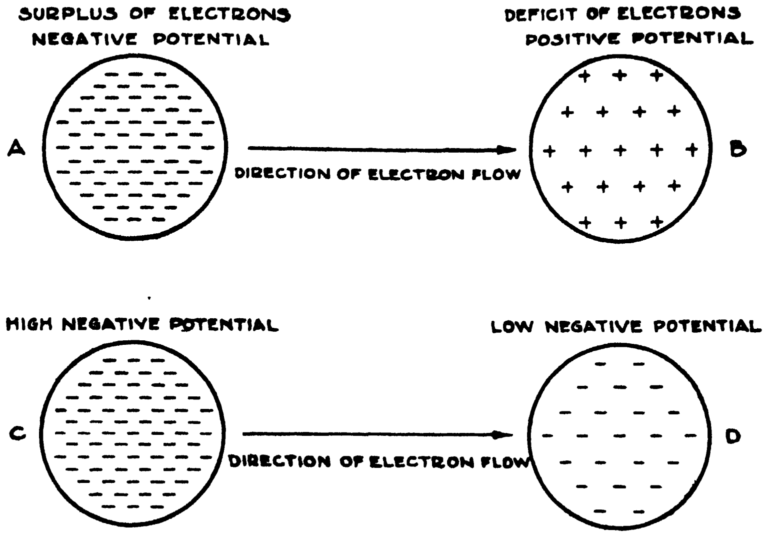


Fig. 1–5. Direction of electron flow, if a path were provided, between bodies charged at different potentials.

occur, one result of which is the recombining of electrons with ions, thus restoring the ions to their uncharged state. As explained in a previous paragraph, the electron does not instantly recombine with the ion but instead oscillates before settling down. The frequency at which it oscillates is such as to produce a wave motion which can be seen as a flash of light. Many thousands of such collisions occur during the discharge period and consequently the intensity of the flash is enormous.

1–3. The Electric Current—It has already been shown in preceding paragraphs that some of the loosely bound electrons can be torn loose from an atom if suitable force is applied. It has also been shown that unlike electrical charges attract while like charges repel.

Let us assume that a metal wire is connected across the terminals of a source of electrical potential as shown in Figure 1–6. A battery is shown in this illustration, but any other source of electrical potential would also be suitable. It will be noted that the battery causes a positive potential to be applied to one end of the wire and a negative potential to the other end. Under these circumstances, the loosely bound electrons in the atoms of the wire are attracted by the positive charge at one end of the wire and repelled by the negative charge at the other end. Some of these electrons, therefore, are torn loose, and a slow and orderly drift of the loosely bound electrons (which are now unbound electrons) through the wire toward the positive terminal of the battery results. Upon reaching the positive terminal, this flow of electrons continues through the battery and back through the conductor.

The actual number of electrons moving under the influence of the charge is determined by the magnitude of the electrical pressure. If a large pressure is applied, the force is great enough to dislodge many electrons and the number of moving electrons is high. With small pressure, the number of moving electrons is low.

Although electricity is assumed to travel at the speed of light, the movement or drift of the electrons through a conductor is quite slow, being in the order of a fraction of a centimeter per second. It is the simultaneous movement of electrons at all points along the entire length of a conductor that makes the current effective at great distances at incredibly fast speeds.

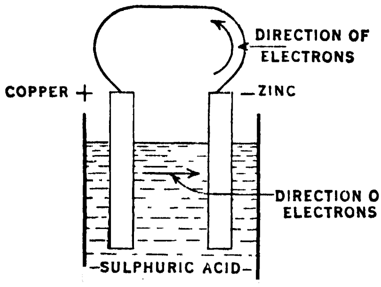


Fig. 1–6. Flow of electrons through conductor is in negative to positive direction.

The movement of electrons through the wire constitutes a flow of electric current. It will be recalled that each electron contains a small electric charge expressed as 1.6×10^{-19} coulomb. The coulomb, symbol Q, is the unit of electrical quantity. The practical unit of current flow is the ampere, which is the rate that the current flows past a given point in the circuit each second; that is, the number of coulombs flowing per second.

1–3a. Direction of Current and Electron Flow—Before the discovery of the electron, it was assumed that the flow of current was from the point of positive potential to the point of negative potential. At this date, however, all scientists agree that the electrons in motion are the current and therefore current flows from a negative to a positive potential. Later on it will be shown how well this fits in with the explanation of the movement of electrons in a vacuum tube.

1–3b. Conductors and Nonconductors—In order for an electric current to flow, it is necessary that a suitable path be provided. Some materials, notably pure metals, are made up of atoms in which a large number of the outermost electrons are loosely bound and therefore move freely through the material when a potential is applied. These materials are known as *conductors.* Other materials are made up of atoms in which all the electrons are closely bound to the nucleus, practically no electrons being free to move when a potential is applied. Such a material obviously will permit very few, if any, electrons to move and is therefore a ***nonconductor.*** Other terms applied to nonconductors are "insulators" and "dielectrics."

Different materials permit varying degrees of conductivity; therefore, some materials are good conductors, others are poor conductors, whereas still others are nonconductors.

1–4. Units of Electrical Measurement

1. *Current.* Electrical current strength is measured in *amperes.* One ampere is flowing when 6,250,000,000,000,000,000 electrons pass a given point in a circuit in one second. This gives some idea of the very small electrical charge on a single electron. The electrical symbol for current is *I.*

2 *Pressure.* The difference of potential between two bodies or between two points of the same body is measured in *volts.* Because a difference of potential will always cause a current to flow, provided a path is furnished, it is also called electromotive force (e.m.f.), the force of which makes the electrons move. Therefore, a volt is the unit of e.m.f. The electrical symbol for electromotive force is *E.*

3. *Resistance.* The property of a material by which it opposes the passage of an electrical current is called resistance and is measured in ***ohms.*** The electrical symbol for resistance is *R.* The resistance of a column of pure mercury 106.3 cm long, weighing 14.4521 g, at a temperature of 32° F, is one ohm. Since the resistance of any metal rises when the metal is heated, our standard ohm must always be measured at the same temperature; for this reason, the temperature of 32° F (0° C) has been chosen.

The resistance of a conductor depends upon the material in the conductor, the length of the conductor, the cross-sectional area, and to some extent upon the temperature of the conductor. To be exact, it increases with the length of the conductor and decreases with an increase of cross-sectional area. Resistance also increases as the frequency is increased.

1–5. Ohm's Law—A simple relationship exists between voltage, current, and resistance. This relationship, which is known as Ohm's law, makes it possible to find any one value if the other two are known. Ohm's law states:

$$I = \frac{E}{R}$$

that is, current (in amperes) equals electromotive force (in volts) divided by resistance (in ohms).

By transposing, Ohm's law can be stated in three ways, as follows:

STANDARD UNITS	FORMULAS	EXAMPLES
$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}$	$I = \frac{E}{R}$	$5\text{ Amperes} = \frac{10\text{ Volts}}{2\text{ Ohms}}$
Volts = Ohms × Amperes	$IR = E$	5 Amperes × 2 Ohms = 10 Volts
$\text{Ohms} = \frac{\text{Volts}}{\text{Amperes}}$	$R = \frac{E}{I}$	$2\text{ Ohms} = \frac{10\text{ Volts}}{5\text{ Amperes}}$

1–6. Production of Electric Current—From the foregoing discussion it is seen that a current will flow through a conductor if there is a difference of potential created. The current will be maintained if the difference of potential is maintained. Take a zinc and a copper rod and immerse them in a sulphuric acid solution. Test the ends of the copper and zinc for charges and it will be found that the copper has a positive charge and the zinc a negative charge. Therefore, a difference of potential exists. Connect the copper and zinc by a wire and a current will flow. Disconnect the wire and test the copper and zinc again. The result will be the same, that is, this combination will maintain a difference of potential and hence will produce a steady current.

The sulphuric acid attacks the zinc (chemical action) and gives it electrons, taking them away from the copper. Such an arrangement is called a cell. (See Figure 1–6.) Two or more cells together are called a battery. There are many combinations of materials that will give the same result. The combination always consists of two dissimilar metals and an acidic or basic solution. The voltage of such a cell is never greater than 2 volts. Such cells are called primary cells. The difference between a primary cell and a storage cell lies in the fact that the primary cell cannot be renewed by passing an electric current through it while a storage cell can. Zinc is employed in all cells, other than storage cells, in common use. It is always the negative pole or terminal. The positive pole is usually copper or carbon.

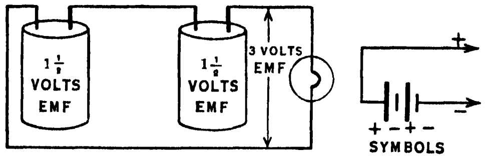
1–6a. Series and Parallel Connections

Cells. Cells may be connected in series or parallel (Figure 1–7). When connected in series the resultant voltage is the sum of the voltages of each cell. When connected in parallel the resultant voltage is the same as that of one cell but the current obtainable is the sum of the current obtainable from each cell.

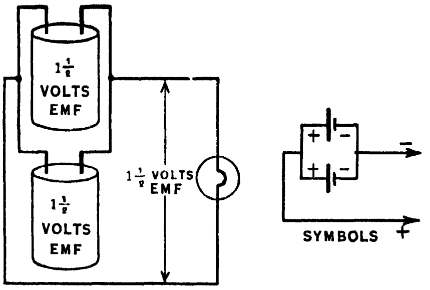
Resistances. Resistances connected in series have a greater resistance than any one alone. Their total resistance is the sum of the individual resistances, that is:

$$R = R_1 + R_2 + R_3$$

Two resistances connected in parallel have a smaller total resistance than either of them. If they are of equal values, the total resistance is one half of the resistance of one. If there are three resistances of equal values the total resistance would be one third of the resistance of one.



SERIES CONNECTION OF CELLS



PARALLEL CONNECTION OF CELLS

FIG. 1-7. Series and parallel connection of cells.

When the resistances are of unequal values their total resistance may be computed as follows:

$$R = \cfrac{1}{\cfrac{1}{R_1} + \cfrac{1}{R_2} + \cfrac{1}{R_3}}$$

where R = the total resistance.

Example: Resistances of 4 ohms, 6 ohms and 8 ohms are placed in series. Their total resistance is $4 + 6 + 8 = 18$ ohms. Connected in parallel, their total resistance is:

$$R = \cfrac{1}{\cfrac{1}{4} + \cfrac{1}{6} + \cfrac{1}{8}} = \cfrac{1}{\cfrac{13}{24}} = 1.8 \text{ ohms}$$

It can be seen that two or more resistances in parallel will conduct an electric current more freely than one.

1-6b. Effects of Current—The passage of current through a conductor can be determined by two principal effects:

1. Heating effect.
2. Magnetic effect.

When a current of electricity flows through a conductor, it encounters frictional resistance and a certain amount of energy is transformed into heat. The heat generated increases directly as the resistance; also the heat generated increases directly as the square of the current, and the time during which the current flows. This is expressed:

$$J = I^2 \times RT$$

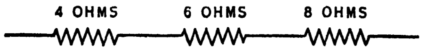
where J is the joule
I the current
R the resistance
T the time in seconds

The joule is defined as that amount of energy which is expended during one second by a current of one ampere flowing through a resistance of one ohm. The joule per second is the practical unit of electrical power which has been named the *watt,* the symbol for which is W.

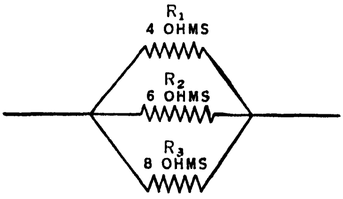
Since power is the rate of doing work per unit of time, one watt per second would equal one joule. The power may be also expressed in the units of electromotive force and current strength. The power in watts in a given circuit in which direct current is flowing is equal to the product obtained by multiplying the current in amperes by the electromotive force in volts or:

$$\text{Watts} = I \times E$$

RESISTANCES IN SERIES



TOTAL RESISTANCE 18 OHMS



RESISTANCES IN PARALLEL
TOTAL RESISTANCE 1.846 OHMS

FIG. 1-8. Series and parallel connection of resistance.

1-7. Magnetism—The magnetic effect resulting from the flow of current through a conductor may be described as follows:

Figure 1-9 shows a coil of wire wound around a soft iron bar and carrying a steady current furnished by the battery. While the current is flowing, the bar will be found to have acquired the power to attract pieces of small steel or iron. If the current from the battery is broken, the bar will lose the power of attraction for the iron or steel. Thus the current flowing through the solenoid has given it a new property called magnetism, and since it has this property only when the electric current flows, it is called an *electromagnet.*

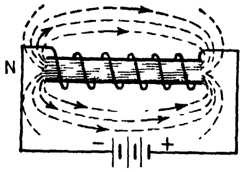


Fig. 1–9. Electromagnet.

If the bar of soft iron is replaced by a bar of hard steel and the current is permitted to flow through the solenoid for a short length of time, it will be found that the steel retains the property of attraction long after the battery circuit is broken. A bar of magnetized steel which retains its magnetism is called a *permanent magnet.*

It will be found that the iron likewise has retained the property of attraction, but to a much smaller degree than the hard steel. The steel is said to have a high degree of retentivity, while the iron has but little retentivity.

The lines of force retained by a piece of iron after the magnetizing current has been discontinued are called the *residual lines of force,* and the iron is said to have *residual magnetism.* Residual magnetism plays an important role in the operation of some types of generators which will be described later.

If a permanent magnet is placed into a box of iron filings, it will be noticed that there are two places on the magnet to which the iron filings cling most strongly. These are near the ends of the bar and are called the *poles* of the magnet.

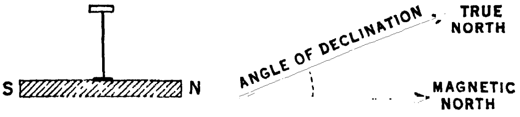


Fig. 1–10. Suspended magnet attracted by earth's magnetic pole.

The poles always appear in pairs and are called the *north pole* and *south pole* because of the folfollowing fact: If the magnet is suspended in such a way that it is balanced and free to turn in a horizontal plane as in Figure 1–10, it will be noted that the magnet will always come to rest pointing in an approximate north-south line. The same end or pole will always point northward; this is called the north or north-seeking pole, while the other end is called the south or south-seeking pole.

The following experiment will indicate the power of attraction and repulsion of the poles of magnets. The north pole of the suspended magnet will be repelled when approached by the north pole of another magnet; likewise, the south pole will be repelled when approached by another south pole, whereas if the north pole is approached by a south pole the suspended magnet will be attracted. If the south pole of the suspended magnet is approached by a north pole the suspended magnet will again be attracted. From this experiment it will be found that like poles repel; unlike poles attract. This clarifies somewhat a statement in the preceding paragraph wherein it was noted that the end of the magnet pointing toward the earth's north pole was the north-seeking pole. It is commonly called the north pole of the magnet, but according to the theory of attraction and repulsion, a north pole could not be attracted by the earth's north magnetic pole.

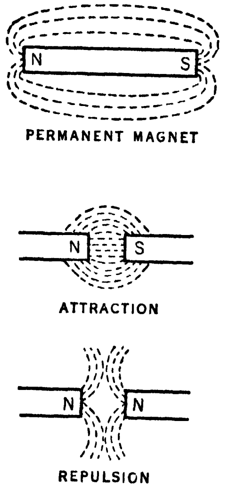


Fig. 1–11. Magnetic fields.

1–7a. Angle of Declination—A magnet balanced upon a pivot and free to swing in a horizontal plane is called a compass. It aligns itself in a north and south direction. This is explained by the fact that the earth has magnetic poles. These magnetic poles are near, but do not exactly coincide with, the geographical poles. Hence, there is an angle between true north and the direction in which the compass points, magnetic north. This angle is called the *angle of declination.*

1–7b. Magnetic Field—If the field surrounding a magnet were to be examined (this can be done with the aid of iron filings), it would be found to consist of closed lines known as magnetic lines of force. These magnetic lines of force extend into the space surrounding the magnet, starting at the north pole, re-entering the magnet at the south pole, and returning through the magnet to the north pole (Figure 1–11). The shape of the external field may be altered somewhat by the presence of near-by magnetic substances. The space through which the lines of force pass is called the *magnetic field.*

1–7c. Permeability—The extent to which a body will be acted upon by a magnet depends upon its ability to carry magnetic lines of force. This property of carrying lines of force is called *permeability.* Different kinds of iron have different degrees of permeability. The magnetic strength of an electromagnet or solenoid varies as the product of the amperes passing through the conductor and the number of turns of wire, commonly called *ampere turns.* For example 100 amperes flowing through 50 turns of wire gives the same magnetic field as 20 amperes flowing through 250 turns, for 100 × 50 and 20 × 250 both equal 5000.

The magnetic strength of such a coil is also dependent upon the permeability of the iron; that is, the iron, in effect, increases many times the lines of force.

1–7d. The Molecular Theory of Magnetism—The following experiments provide a basis for the presently accepted theory of magnetism.

1. Take a magnet and strike it repeatedly. The magnetism will gradually disappear.
2. Take a bar magnet and cut it into small pieces. Each piece, no matter how small, will be a magnet.
3. Take a magnet and heat it. The magnet becomes very much weaker and eventually loses its magnetism.
4. Take a piece of steel and stroke it with a magnet. The steel will become a permanent magnet.

When it is remembered that heat is caused by the rapid vibration of the molecules of which a body is composed, and that the final division in cutting a magnet into minute pieces would also reduce it to molecules (if this were possible) it is easy to draw the conclusion that each individual molecule of which the material is composed is actually a small magnet. Hence, this theory is known as the molecular theory of magnetism.

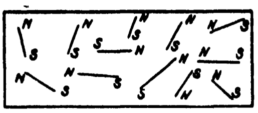


Fig. 1–12a. Arrangement of molecules in unmagnetized iron bar.

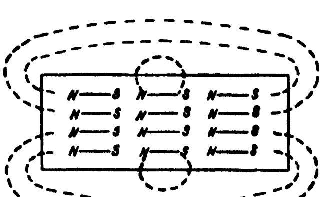


Fig. 1–12b. Arrangement of molecules when iron bar is magnetized.

According to the molecular theory of magnetism, it is assumed that each molecule of a magnetic material is a small magnet possessing a north and south pole. If this is true, then why is it that a bar of iron is not always a magnet?

Consider the diagram of Figure 1–12a. The small lines represent the molecules. It is seen that if they are arranged in a haphazard manner the lines of force emanating from one molecular magnet go to the nearest south pole of another molecular magnet and so on back to their origin without extending outside the iron bar. Hence, there are no magnetic lines of force outside the iron bar. Therefore, it is not a magnet.

If the iron bar is magnetized, the molecules arrange themselves in an orderly manner, as shown in Figure 1–12b. The magnetic lines of force emanating from one molecular magnet pass to the next one, and then to the next, and to get back to their source must go outside the iron, for they cannot double back on themselves. Hence, the iron bar is now a magnet.

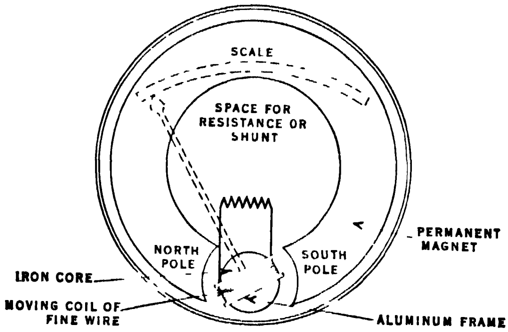


Fig. 1–13. Meter with D'Arsonval movement.

1–8. Voltmeters and Ammeters—The fact that an electric current is surrounded by a magnetic field is used in the construction of voltmeters and ammeters. The simplest kind of an ammeter is made by placing a compass in the center of a coil of wire. The greater the strength of current, the greater the needle deflection.

Another type of ammeter, and the one most commonly used, is made by having the magnet stationary and the coil movable. The moving coil principle was developed by a French scientist named D'Arsonval and is therefore known as the D'Arsonval movement. Figure 1–13 shows the arrangement of this instrument.

Between the pole faces of a permanent magnet is placed an iron core, allowing a gap between it and the pole faces large enough to permit an aluminum frame to swing freely. On this frame is wound a coil of very fine wire, through which a certain percentage of the current to be measured passes. As this current passes through the coil, the coil becomes an electromagnet with north and south poles which are immediately affected by the north and south poles of the permanent magnet. Obeying the magnetic law that like poles repel and unlike poles attract, the north end of the electromagnet is drawn toward the south pole of the permanent magnet and vice versa—which results in the aluminum frame being moved and the pointer attached to the frame moving across the scale. Every meter of this type is in reality a millivoltmeter (millivolt—1/1000 of a volt) as the coil is built in such a manner that a small current flowing through it causes the action described.

Permanent magnets can be weakened by jarring and age; hence, high grade meters use carefully aged tungsten steel magnets.

1–8a. Use of Shunt and Multiplier—A voltmeter is always shunted (connected in parallel) across the load whose voltage is to be measured. The voltmeter has a very high resistance, sometimes requiring the use of an external series resistor. When possible, this resistance is mounted within the meter case. Because of its high resistance, the voltmeter requires a very small current for its operation.

The ammeter is always connected in series with the load. It has a low resistance. In some ammeters only a fractional part of the total current passes through the coil, the remainder being conducted by a shunt which is calibrated for the particular ammeter.

An example will show how these meter resistances and shunts are calibrated.

Let us assume that the coil of a meter is wound with 10 ft of fine wire having a resistance of 10 ohms. It is found by experiment that 0.1 volt (100 millivolts) is required to move the needle of the meter to full-scale deflection. Then, according to Ohm's law, $I = E/R$, or $I = 0.1/10 = 0.01$ amp, the current required to cause full-scale deflection.

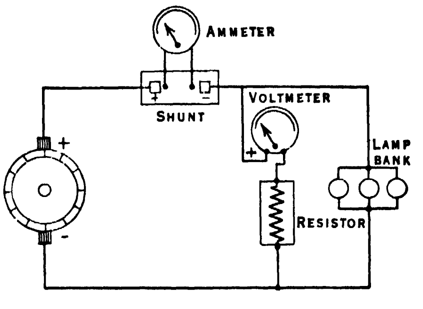


FIG. 1–14. Method of connecting voltmeter and ammeter. Voltmeter employing resistor and ammeter employing shunt.

If it is desired to use the above meter in an application where the full scale reading is to be 5 amp, it is necessary to connect a shunt across the meter to carry a large portion of the current. In this case, the shunt must have a resistance value such that 4.99 amp will flow through the shunt, while only 0.01 amp flows through the meter. Figure 1–14 shows such an arrangement. The resistance of the shunt must be 1/499 of the meter resistance, or in this case 10/499 = 0.02004 ohm.

1–9. Telephone Receivers—The telephone receiver illustrates another application of the property of magnetism. The telephone receiver, as used for telephone work, consists of a case containing a permanent horseshoe magnet, two coils of wire, and a soft-iron diaphragm, the latter being clamped by its rim with its plane at right angles and close to, but not touching, the poles of the permanent magnet. The extensions on the permanent magnet are fitted with bobbins which are wound with many turns of fine wire. The diaphragm is left free to vibrate except at its rim. The distance from the pole pieces to the diaphragm is normally fifteen thousandths of an inch (.015 inch). (See Figure 1–15.)

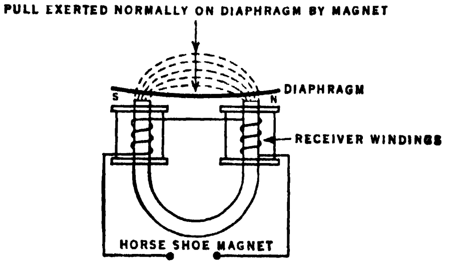


FIG. 1–15. Construction of telephone receiver.

The action of the receiver is as follows: The permanent magnet attracts the diaphragm of the receiver, holding it under a steady attraction. If a varying or alternating current passes through the coils of the receiver, the strength of the magnetism is varied. The pull on the diaphragm is therefore varied and, if the changes in the current passing through the coils are rapid, they will cause the diaphragm to vibrate accordingly. Thus, if the current passing through the coils is varied at the frequencies used in speech, the diaphragm will vibrate accordingly, reproducing the voice of the speaker.

The diaphragm is lacquered on one side and enameled on the other. As the efficiency of a receiver depends greatly upon the smallest practical air gap, the side nearer the magnet is coated with lacquer, which is much thinner than the coat of enamel on the other side. The lacquer and enamel serve to protect the diaphragm from rust. The pole pieces of the magnet are lacquered for the same purpose.

As the receiver has a permanent north and south pole, current flowing in a given direction will either increase or decrease the strength of both poles, the coils being so connected to accomplish this.

The distinctive features of telephone receivers for radio work are lightness of the moving parts and the employment of a great many turns of wire around the magnet poles. The lightness of the diaphragm enables it to follow and respond to rapid pulsations of current. The large numbers of turns of wire causes a relatively large magnetic field to be produced by a feeble current.

1-10. Induction—An important discovery in electricity revealed the fact that a magnetic field in motion would cause a movement of electrons, that is, produce a flow of electric current (Figure 1-16). The following experiment will illustrate this fact.

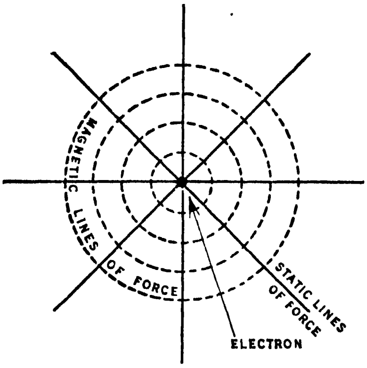


Fig. 1-16. Electron in motion produces magnetic lines of force.

Take a coil of wire, as in Figure 1-17, lower a magnet end into the coil. The pointer of the milliammeter will move, indicating the presence of a current. It will quickly come to rest. Draw out the magnet. The needle moves again; but this time in the opposite direction. Reverse the magnet and repeat the above. It will be found that the meter pointer moves, but in the opposite direction to its movement before the magnet was reversed. Use two magnets. The meter pointer deflects farther than with a single magnet. Try moving the magnet faster and slower; the faster it moves the more the needle moves—i.e., the stronger the current. Notice that a current flows only when there is relative movement between the magnet and the coil. Try moving the coil instead of the magnet—the results are the same.

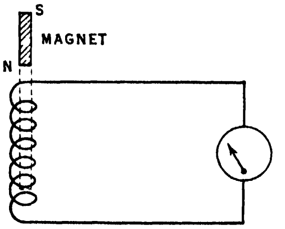


Fig. 1-17. Production of current by electromagnetic induction.

Substitute a piece of unmagnetized steel for the magnet. There is no current. The difference between the magnet and the unmagnetized steel is that the magnet is surrounded by magnetic lines of force.

These experiments show that whenever a conductor is cut by magnetic lines of force there is a current produced by *electromagnetic induction.* Investigate further by having a current produce the magnetic lines of force, they in turn producing a current. Substitute an electromagnet for the magnet used in the previous experiment. Arrange a circuit as in Figure 1-18. Press the key. The meter pointer moves in one direction and then comes to rest. Break the current by means of the key—the meter moves in the opposite direction and then comes to rest. Insert an iron core in the coil of wire. The results are similar but the current induced is much stronger.

In this experiment the conductor has been cut by magnetic lines of force. The circuit with the key is called the primary circuit; the other, the secondary circuit. Closing the circuit in the primary allows a current to pass which sets up a magnetic field. This magnetic field cuts the secondary, thus inducing a current. When the primary circuit is broken, the magnetic field collapses, and the secondary is again cut by lines of force, this time in the opposite direction.

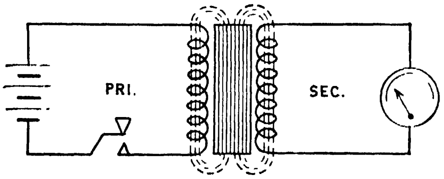


Fig. 1-18. When current is started or stopped in the primary circuit a voltage is induced in the secondary by electromagnetic induction.

All these experiments produce current by electromagnetic induction. The facts of electromagnetic induction may be summed up as follows:

Whenever variable magnetic lines of force cut a conductor or a closed circuit made by a conductor, there is created in the conductor an e.m.f. whose direction is such as to oppose the e.m.f. that produced it. The value of this back e.m.f. is proportional to the rate of change of the lines of force.

1-10a. Self-Induction—Consider the circuit shown in Figure 1-19. Close the key, and a current will flow through the circuit. This current does not flow instantaneously. It reaches point *A* before *B*. The current passing through the turns of the coil sets up magnetic lines of force which cut the turns of wire, producing an e.m.f. whose direction is such as to oppose the passage of the original current in the circuit. When the key is opened, the lines of force collapse on the coil, inducing an e.m.f. in the same direction as the original current tending to keep the current flowing. Induction in the same circuit is called *self-induction.*

1-10b. Mutual Induction—Mutual induction is the interaction between two circuits by which a changing current in one sets up through electromagnetic induction a current in the other. Consider the circuit in Figure 1-20. Whenever the current is started, stopped, or varied in the primary coil, the magnetic lines of force set up around it cut the windings of the secondary, inducing an e.m.f. in the secondary circuit. A transfer of electrical energy has taken place between two circuits which have no electrical conducting path between them. Induction between two separate circuits is called *mutual induction.*

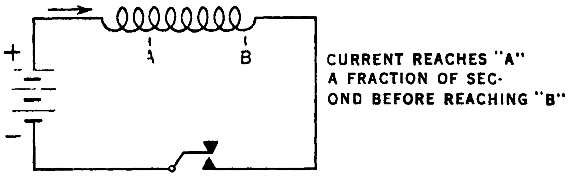

A
B
CURRENT REACHES "A" A FRACTION OF SECOND BEFORE REACHING "B"

Fig. 1-19. Counter e.m.f. of self-induction.

The mutual induction of two given circuits depends upon the size and construction of the circuits, their distance apart, their relative positions in space, and the nature of the material between them. All these factors necessarily affect the magnetic flux interlinked with both circuits. The effects of mutual inductance fall off rapidly as the distance between two circuits is increased. Mutual inductance is measured in the same unit as self-inductance.

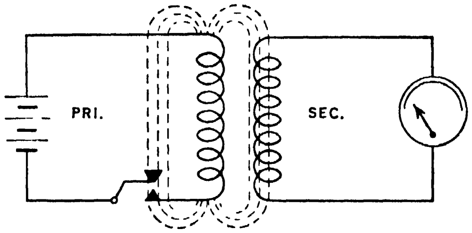


Fig. 1-20. Induced current by mutual induction.

Mutual inductance is of importance in radio circuits. The phenomena of mutual inductance are the essential principles involved in the operation of many different types of electrical apparatus, of which some are considered in the following pages.

1-11. Inductance—Inductance is electrical inertia and is defined as that property of a circuit which opposes a change in flow of current through the circuit.

Opposition to a change in the flow of current depends upon the amount of self-inductance or upon the combined amount of self-inductance and mutual inductance. The inductance of a circuit is, therefore, the amount of self-inductance it possesses plus any mutual inductance which it may also possess. The unit of inductance is the *henry,* abbreviation for which is h.

A circuit has an inductance of one henry when a current changing at the rate of one ampere per second induces an e.m.f. of one volt.

At radio frequencies where small values of inductance are employed the unit is subdivided and expressed as follows:

1 millihenry (mh)—.001 h.
1 microhenry (μh)—.000001 h.

In self-induction this e.m.f. is set up as a counter e.m.f. in the circuit itself; in mutual induction, it is set up in the secondary circuit. In either case its effect is to oppose any change of flow of current through the circuit and is the measurement of opposition to that change. In any given conductor, the time it takes for the current to build up to its maximum or to decrease to zero is influenced by the opposition to its increase or decrease in strength, that is, it is influenced by the inductance of the conductor. The greater the inductance, the longer the time required for the current to reach its maximum strength.

The inductance of a circuit, conductor, coil, or of any apparatus is a property of that device, just as resistance is one of its properties. The impressed voltage does not affect the inductance. A conductor has inductance whether or not current flows in it.

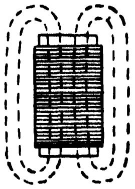
1-11a. Practical Forms of Inductors—The inductors most commonly employed at radio frequencies consist of a single-layer coil wound as an air-core solenoid. Other forms consist of multi-layer coils either in the form of spider web or honeycomb coil, so called because of their physical construction. In addition there have appeared the toroidal and the binocular coil, so called because of their shape.

The extent of the magnetic field can be greatly restricted by altering the shape of the coil. By bending the coil into the shape of a "toroid" as *b,* Figure 1-21, the field or magnetic flux is circulated around the center of the coil and confined to the limits of the coil.

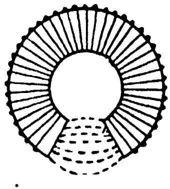
Another scheme used to confine the magnetic field of a coil is the binocular coil. This form of coil is shown in *c,* Figure 1-21. Here the coil is divided in two with the two halves placed side by side, the windings of each being connected in series. The flux passes through one half and returns through the other half. Both the toroid and the binocular type coils are used in older radio receivers and their purpose is to confine the magnetic fields of the coils to prevent their reaction on earlier stages of amplification.

Iron-core inductors are made by winding many turns of wire on an iron core. The core may be the open or closed type. It is usually found in audio-frequency circuits. The use of such coils will be shown in later chapters.

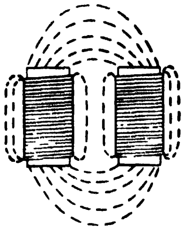
1-12. Capacitance—When water is poured into a container, the pressure in the container depends on how high the level of the water is raised; the pressure will be directly proportional to the quantity of water in the container, and inversely proportional to the container's size and shape. The size and shape will qualify what might be called the capacity for water of the container. If the container is connected to a tank containing water, a discharge will flow into it until the levels or pressures are the same in both, and the greater the capacity of the container the more water will flow into it to equalize the pressures.



a—Single layer solenoid.



b—Toroidal coil.



c—Binocular coil.

FIG. 1-21. Practical forms of inductance coils showing electromagnetic field surrounding each.

1-12a. Dielectric Current—Similarly, if a perfect insulating material, with no other conductors near by, is charged by connecting it by contact or by a wire to a source of e.m.f., a charge will flow into it until the two are at the same potential. A small sensitive indicator of current connected as in Figure 1-22 will show a sudden deflection each time the key is closed and will soon return to zero. The momentary flow of current is due to the production of an electric strain or displacement of electricity. This is resisted by an elastic reaction of the insulator that may be called electric stress. Because of this reaction of the electric stress, the electric strain due to a steady applied e.m.f. reaches a steady value, and the current becomes zero. When the electric strain is allowed to diminish a current again exists in the opposite direction. A current of this kind, called a displacement current, exists only when the electric strain or displacement is changing. When considering the existence of electric strain or displacement in an insulating material, the material is called a *dielectric* and the displacement current is sometimes called a *dielectric current.* The electric displacement is a movement of electrons, with the positive elements of each molecule of the substance gathered at one end, and the electrons at the other. A dielectric in such a strained condition possesses a charge of electricity and is sometimes called electricity in electrostatic form, or electricity at rest.

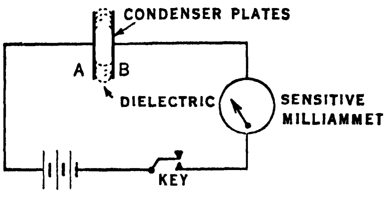


FIG. 1-22. Production of displacement current in a condenser.

1-12b. Condensers—A condenser, or capacitor, is constructed of several conductors placed parallel to each other and separated by an insulator called the dielectric. It usually takes the form of one metallic plate, or set of plates, joined together and separated from a similar plate or set of plates by a dielectric glass, ebonite, paraffin, oil, mica or air.

The capacitance of a condenser depends on:

(*a*) The area of the plates.
(*b*) The distance between the plates.
(*c*) The material of the dielectric.

If an experiment is made of the effectiveness of glass and air as the dielectric, it will be found that the glass increases the capacitance 4 to 10 times as much as air.

The dielectric constant of a substance is, therefore, its effect when used as a dielectric as compared with an air dielectric. The following table shows the dielectric constants of several materials.

Material	*Dielectric Constant*
Air	1.0
Glass	4.0 to 10
Mica	4.0 to 8
Hard rubber	2.0 to 4
Paraffin	2 to 3
Paper, dry	1.5 to 3
Paper (treated as used in cables)	2.5 to 4
Moulded insulating material, shellac base	4 to 7
Moulded insulating material, "Bakelite"	5 to 7.5
Transformer oil	2.5
Polystyrene	2.5 to 3
Mycalex	8.0
Fused quartz	4.0
Isolantite	6.1

A wide variation is seen in the values given for some materials. The different grades and kinds of materials vary considerably in their physical properties, including their electrical properties. For instance, glass used for photographic plates has a higher dielectric constant than that of common window glass. Moulded insulating material, known to the trade as bakelite, has a much higher dielectric constant than substitutes commonly spoken of as moulded mud.

If the applied voltage is from a source of alternating current, the values of dielectric constant may differ from the values obtained with direct current. This is particularly true if the alternating current has a very high frequency, such as used in radio communication.

Dielectric materials are not perfect insulators but do have a very small conductivity. A charge in a condenser will be slowly dissipated if allowed to stand with its terminals disconnected. This is called leakage. A condenser in which the dielectric is paper which has not been properly treated will sometimes discharge within a few minutes because of leakage. The lower the leakage, the longer the charge will remain in the condenser.

The thinner the dielectric, everything else remaining equal, the greater the capacitance. The breaking-down potential of a dielectric depends upon its thickness as well as the material; consequently, the thickness of the dielectric which must be used depends on the potential strain it will be required to stand, as well as the material used. Thus, the dielectric strength is measured by the voltage which will break down the insulation of a unit thickness of the material. The values vary somewhat according to the shape of the electrodes between which the dielectric is placed. Thus, when capacitance is increased by decreasing the thickness of the dielectric for a given potential, there is a certain thickness for each dielectric that may be used, and the best dielectric has not necessarily the highest dielectric strength.

The larger the capacitance of a condenser, the greater the charge required to bring it to a given potential. Thus, the potential is directly proportional to the charge and inversely proportional to the capacitance, or in symbols:

$$E = \frac{Q}{C} \quad \text{or} \quad C = \frac{Q}{E} \quad \text{or} \quad Q = C \times E$$

where E = potential
Q = quantity or charge
C = capacitance

Unit capacitance would be that of a condenser which is raised to unit potential by unit charge. The practical unit of capacitance is called the *farad*, the abbreviation for which is f. A condenser whose capacitance is one farad would be raised to a potential of one volt by a charge of one coulomb. A farad is far too large a unit for ordinary purposes and the following subdivisions are generally employed in practice:

μf = .000001 farad,
[1] $\mu\mu$f = .000000000001 farad.

1-12c. Dielectric Hysteresis—If a charged condenser is discharged and left undisturbed for, say, 30 seconds, another small discharge can be obtained from it, and sometimes a third one. This is due to the fact that, when charged, the strain across the dielectric causes the charges to leave the plates and settle on the surface of the dielectric, through which they are bound by electric lines of force, or strain in the dielectric. When the plates are suddenly discharged, the electrons rushing around the circuit neutralize the positive and negative charges but some are still left straining across the dielectric, trying as it were to get across that way instead of taking the easier path that has suddenly been provided for them; the dielectric does not entirely recover from the strain when the discharge takes place. The charge which flowed out instantaneously upon discharge is called the *free charge*. The charge which flows out the second or third time is called the ***absorbed*** or *residual charge*. In condensers made with oil or mica for the dielectric, absorption is small. This absorption is manifested by heat in the dielectric and represents a loss of energy.

1-12d. Series and Parallel Connection of Condensers—Condensers may be connected either in series or in parallel. If connected in parallel, the combined capacitance is equal to the sum of their individual capacitances, or:

$$C = C_1 + C_2 + C_3$$

Connecting them in parallel is equivalent to adding the plate areas. If three condensers of similar construction, each having a capacitance of .004 μf, are connected in parallel, the resulting capacitance would be .012 μf.

If condensers are connected in series the resulting capacitance is less than that of one alone. If the condensers have equal values of capacitance, their combined capacitance is obtained by merely dividing the capacitance of one by the number of condensers in series; if they have unequal values, the resulting capacitance is equal to the reciprocal of the sum of the reciprocals or,

$$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

If three condensers of .004 μf are connected in series, the resulting capacitance would be .0012 μf. If three condensers of .002, .003, and .004 μf are connected in series the resulting capacitance would be .00092 μf.

The voltage that several equal condensers in series will safely withstand is as many times greater than the voltage of one as there are condensers in series. Advantage is often taken of this in building condensers for high voltages. Using this principle, a .004-μf condenser to stand 20,000 volts can be made of twenty 1000-volt sections of .08 μf each, all connected in series.

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[1] Sometimes written "pfd" meaning picofarad.

Condensers used in radio transmitters are sometimes protected by a safety gap mounted on their terminals. The gap is so spaced that, should the condenser be subjected to an excessive voltage, a discharge will take place across the gap, thus lowering the potential of the condenser and preventing a rupture of the dielectric.

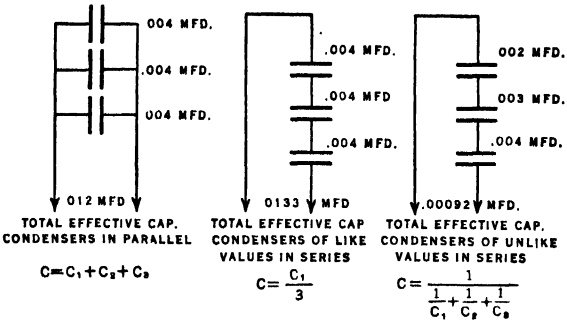

004 MFD.
.004 MFD.
004 MFD.
012 MFD
TOTAL EFFECTIVE CAP. CONDENSERS IN PARALLEL
C=C₁+C₂+C₃
.004 MFD.
.004 MFD
.004 MFD.
0133 MFD
TOTAL EFFECTIVE CAP CONDENSERS OF LIKE VALUES IN SERIES
C= C₁/3
002 MFD.
003 MFD.
.004 MFD.
.00092 MFD.
TOTAL EFFECTIVE CAP. CONDENSERS OF UNLIKE VALUES IN SERIES
C= 1/(1/C₁+1/C₂+1/C₃)

Fig. 1–23. Series and parallel connection of condensers.

It has been shown that a condenser, when first connected to a charging source, has zero potential and as the current flows, the potential rises until the voltage of the condenser is equal to the voltage of the charging circuit; the flow of current then stops. If the charging potential is decreased, the condenser will discharge and current will flow out in the opposite direction to which it was charged. The voltage of the condenser tends to set up a back pressure which tends to drive the charging current back. The effect of capacitance in a circuit increases the time required to obtain a maximum flow of current through the circuit. Inductance in a circuit tends to prolong the flow of current while capacitance tends to extinguish it or hold it back. The effects of counter e.m.f. of inductance and capacitance produce a pronounced effect on the flow of alternating current.

1–13. Alternating Current—An alternating current is a current that reverses its direction of flow at regular intervals. The wave form of the commercial alternating current commonly used for light and power is a sine wave, Figure 1–24. Although the wave shape of an alternating current may deviate considerably from the true sine-wave form, this form is assumed in most a-c calculations.

Starting at zero potential, the alternating current flows in one direction, reaches a maximum value, then returns to zero only to flow again but this time in the opposite direction, reaching a maximum value in this direction and then returning again to zero. This constitutes one complete *cycle*.

Each cycle is composed of two alternations. One alternation is the flow of current in one direction, starting from zero rising to a maximum value and returning to zero again. The peak value of current reached during an alternation is called its *amplitude*. The number of complete cycles occurring during a second of time is called the *frequency* of the current. Thus, a 500-cycle generator produces 1000 alternations of current per second.

It can be shown that the voltage and current wave form of an alternating current may be irregular or distorted in form and if pictured graphically will show, besides the fundamental, other frequencies which are multiples of the fundamental. These are known as *harmonics*. If a harmonic is double the frequency of the fundamental it is known as the second harmonic; if three times, the third harmonic, and so on. Harmonic frequencies are quite common to radio-frequency currents, as will be shown later.

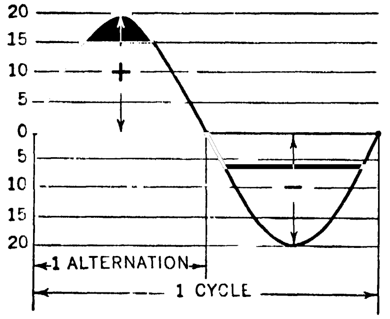


Fig. 1–24. Curve of one complete cycle of of alternating current.

Alternating currents having a frequency below 15,000 cycles per second are called *audio-frequency currents* and those above 15,000 cycles are called *radio-frequency currents*.

Consider the arrangement shown in Figure 1–25. A small lamp and a condenser of approximately 20 μf are connected in series with an alternating-current generator. As long as the circuit is closed, the lamp will be lighted, indicating the passage of current.

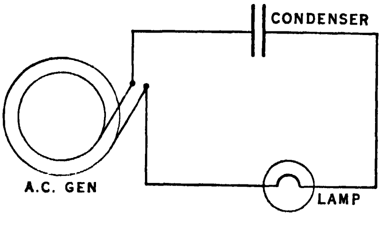


Fig. 1–25. Condenser in series with a-c circuit.

If direct current was applied to this circuit, the lamp would be lighted only momentarily when the circuit was closed until the condenser was charged to the same e.m.f. as the applied e.m.f. With an alternating e.m.f. in the condenser circuit the alternating current is constantly flowing into and out of the condenser to keep the voltage between the plates equal to the instantaneous value of the applied e.m.f.

The current is largest at moments when the applied e.m.f. is changing most rapidly; it is zero at moments when the e.m.f. is for a moment stationary at its maximum values.

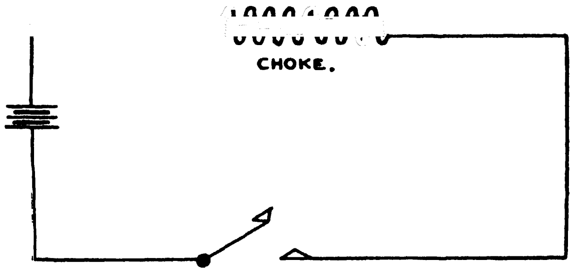


Fig. 1–26. Reactance coil in d-c circuit.

1–13a. Impedance—The flow of direct current through a circuit is opposed only by the ohmic resistance, but the flow of alternating current is opposed by the counter e.m.f. of self-induction as well as ohmic resistance. The effect of self-induction in a direct-current circuit is only momentary, the effects being observed only when the current is changing in value, as would occur when the circuit is closed or opened. Consider the circuit shown in Figure 1–26. The presence of the choke coil retards the flow of current when the key is closed and tends to prolong it after the key is opened. If the battery were to be replaced by an alternating current generator, there would be a constant opposition to the alternations of current, that is, the counter e.m.f. self-induction of the choke would retard an alternation from reaching its maximum amplitude and would also tend to delay it from falling to zero. The counter e.m.f. of self-induction is called *reactance* and, as it is a form of opposition, it is convenient to measure it in ohms. The combined opposition of reactance and ohmic resistance is called *impedance* (expressed symbolically as Z). It also is measured in ohms. However, the combined resistance, or impedance, of a circuit in which there are values of reactance and ohmic resistance is not found by adding the values of each but expressed as follows:

$$\text{Impedance } Z = \sqrt{R^2 + X^2}$$

where R = resistance of circuit in ohms
X = reactance of circuit in ohms

The counter e.m.f. occasioned by a circuit containing inductance is termed ***inductive reactance.*** It is expressed:

$$\text{Inductive reactance } X_L = 2\pi fL$$

where 2π = 6.28
f = frequency in cycles per second
L = inductance in henrys

From the formula it can be seen that the higher the frequency, the greater will be the inductive reactance. At radio frequencies the reactance of a given coil reaches high values.

The counter e.m.f. occasioned by a condenser in series with an alternating current is called ***capacitive reactance.*** It is expressed:

$$\text{Capacitive reactance } X_c = \frac{1}{2\pi fC}$$

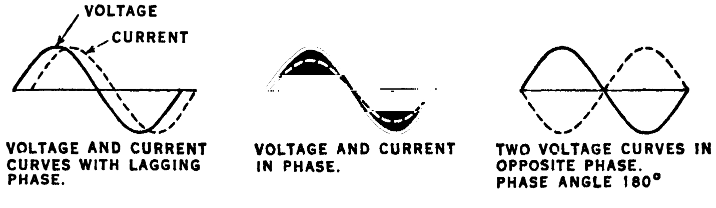
where 2π = 6.28
f = frequency in cycles per second
C = capacitance in farads

A condenser offers less obstruction to the flow of current as the frequency is increased.

1–13b. Phase Displacement—If an a-c circuit contains only resistance, the voltage and current flowing through the circuit reach their maximum and minimum values at the same instant. Under these circumstances, the voltage and current are said to be *in phase.* When inductance is introduced in the circuit, the current reaches its maximum value at a time later than does the voltage, the interval of time depending on the value of the inductance and the frequency of the current. This difference in time is called *phase displacement.* Such a circuit is said to have a *lagging phase.* (See left-hand drawing of Figure 1–27.)

When capacitance is introduced in the circuit and capacitive reactance predominates, the opposite condition will occur, that is, the current will lead the voltage, reaching its maximum at a time before the voltage. A circuit of this type is said to have a *leading phase.*

Difference in phase is nothing more than difference in position of the voltage and current in the cycle. Phase displacement is expressed in terms of the degrees of a circle, that is, an alternating current is said to have an angle of lag of so many degrees, depending upon the constants of the circuit.



VOLTAGE AND CURRENT CURVES WITH LAGGING PHASE.

VOLTAGE AND CURRENT IN PHASE.

TWO VOLTAGE CURVES IN OPPOSITE PHASE. PHASE ANGLE 180°

Fig. 1–27. Curves showing lagging and leading phases.

The effect of phase displacement on the power of the circuit is to reduce the value of power for the same value of current and voltage as compared to the power in a purely resistance circuit. Whenever an a-c load contains reactive elements, the product of E and I will not give the power. This product must be corrected by being multiplied by the *power factor*, which is always smaller than one but is usually expressed in percent. Since one usually does not know the power factor, it is best to use a wattmeter which makes the correction automatically. (See Figure 1-28.)

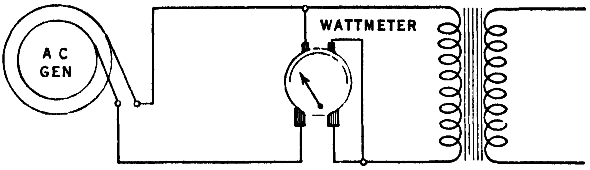


Fig. 1-28 Wattmeter connections.

1-13c. Single and Polyphase Alternating Current—An alternating current having but one e.m.f. is known as a *single-phase* current. An a.c. having two or more e.m.f.'s differing by a fixed amount is called a *polyphase* current.

If three conductors were spaced on an armature 120° apart and revolved between the poles of a U magnet, there would be generated in the conductors three e.m.f.'s differing in phase by 120°. If the three conductors are connected to an external circuit, the system would be known as a three-phase circuit. (See Figure 1-29.)

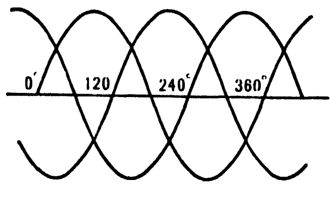


Fig. 1-29. Voltage curve of three-phase alternating current.

1-13d. Effective Value of Alternating Current—An alternating current with a peak value of one ampere obviously will not produce the same power or heating effect that a direct current of one ampere will produce.

The value of alternating current required to produce the same effect is known as the *effective*, or *rms*, value, and this is the value that is indicated on a-c ammeters. The rms alternating current will have the same heating value as the same number of d-c amperes, in other words, one ampere d-c and one effective ampere a-c both produce the same heating effect, or power. The peak value of the alternating current will have a value $\sqrt{2}$, or 1.41, times the effective value.

Example: If 10 amp of direct current pass through a resistance of 2 ohms, the power converted to heat will be I^2R or $10^2 \times 2 = 200$ watts.

If an alternating current is passed through the same resistance and is adjusted to such a value that 200 watts are again consumed in heat, the value of current indicated by an a-c ammeter will be 10 amp. The peak value of this current will be $10 \times \sqrt{2}$, or 14.1 amp.

The abbreviation "rms" represents root-mean-square. The effective, or rms, value of an alternating current is found by extracting the square root of the mean of all the instantaneous values of current over a complete cycle squared.

As shown above, the rms, or effective, value and the peak value of an alternating current are related in the following manner:

$$I_{peak} = I_{eff} \times 1.414$$
$$I_{eff} = I_{peak} \times 0.707$$

The relationship of peak and effective values of voltage are the same as the above current relationship. The maximum voltage per alternation is 1.41 times the effective value. The maximum voltage per alternation in 110-volt a-c circuits is therefore 155 volts.

1-13e. Hot-Wire and Thermocouple Ammeters—Radio-frequency currents are measured by the heating effect of the current on a piece of wire or strip of metal. Such instruments are called thermal ammeters. They are divided into two classes known as *hot-wire* and *thermocouple* ammeters.

The hot-wire ammeter depends for its operation upon the expansion of a metal wire when it is heated. Figure 1-30 illustrates the principle.

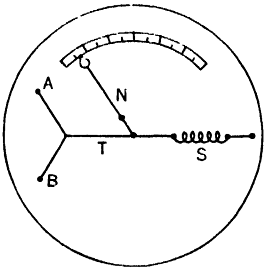


Fig. 1-30. Principle of hot-wire ammeter.

Wire AB is connected with the r-f current. The resistance of the wire is such that it will stretch when heated by the r-f current. Spring S exerts a pulling action on the slackened wire through thread T. The resultant motion causes needle N to move over the scale. The degree of movement depends upon the amount of current flowing in wire AB. The scale is calibrated in amperes so that the position of the needle shows directly how large the current is.

The thermocouple ammeter depends for its action on the e.m.f. produced by heating two dissimilar metals. The value of e.m.f. depends on the combination of metals and ordinarily increases directly as the temperature is increased.

The theory of operation can be explained by referring to Figure 1–31. Two dissimilar metals *C* and *D* make contact with the hot wire *AB*, in which the r-f current is flowing. The e.m.f. produced by the heat at the junction *E* is communicated to the d-c ammeter *M*. As previously explained, the heat due to a given number of amperes of alternating current is the same as that of an equal number of d-c amperes. A deflection of the needle of the ammeter indicates the effective value of current since a-c meters of r-f variety read in effective value just as do 60-cycle or 500-cycle instruments.

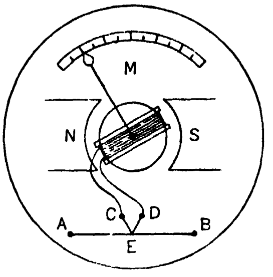


Fig. 1–31. Principle of thermal-ammeter.

1–13f. Skin Effect—The resistance offered by a conductor to r-f current is not the same as for a low-frequency or direct current. The resistance increases with frequency. Radio-frequency currents are conducted on the surface of the wire, hence, it is the surface area and not the cross-sectional area which is most important in determining the resistance to currents of high frequency. Stranded wire, tubing, or metal strip is often used in connecting radio apparatus, because the same amount of copper has more surface in such shapes than when it is formed into solid wire.

1–13g. Resonance in Alternating-current Circuits—It has already been shown that the effects of inductive reactance X_L are opposite than the effects of capacitive reactance, X_C. By the proper selection of inductance and capacitance values in an a-c circuit the counter e.m.f's can be made to balance at any desired frequency and the reactance therefore reduced to zero. The circuit then acts as if neither inductance nor capacitance were present and the flow of current is limited solely by the ohmic resistance. When this condition exists the circuit is said to be *resonant* since the frequency of the circuit corresponds to the frequency of the current flowing in the circuit. The frequency at which this occurs is called the *resonant frequency.*

There is a frequency for each combination of inductance and capacitance where the reactances of each will be equal and opposite. Inasmuch as circuits used in radio work must be capable of resonating over a wide range of frequencies, it is convenient to arrange either the capacitance or the inductance, or both, to be variable so the resonant frequency of the combination can be adjusted to the frequency desired.

Since inductive reactance $X_L = 2\pi fC$ and capacitive reactance $X_C = \frac{1}{2\pi fC}$, the inductive and capacitive reactances will be equal in a circuit containing an inductance and capacitance in series when the following condition exists:

$$2\pi fL = \frac{1}{2\pi fC}$$

where f = frequency in cycles per second
L = inductance in henrys
C = capacitance in farads

From the above equation, the resonant frequency of a given value of capacitance and inductance in series can be found. Transposing, the above equation becomes

$$f = \frac{1}{2\pi\sqrt{LC}}$$

The above equation for resonant frequency is strictly correct only for series-connected inductances and capacitances. When parallel-connected, the resonant frequency is affected to some extent by the resistance in the circuit. If the resistance is low, as is usually the case in radio circuits, the formula for series resonance may be used with reasonable accuracy.

1–14. Alternating-current Transformers—There are two kinds of alternating-current transformers commonly employed in radio telegraphy and telephony. The purpose of one is to change or transform alternating current of low voltage and comparatively large current to alternating current of higher voltage and smaller current or vice versa.

The transformer which is used to produce a higher voltage is called a *step-up* transformer. A transformer used to produce a lower voltage than the input is called a *step-down* transformer.

The step-up transformer is generally employed to produce high voltages for the plate supply of vacuum tube transmitters. The step-down transformer is used to operate the filaments of vacuum tubes.

1–14a. Construction—An a-c transformer consists of two windings so placed as to have appreciable mutual inductance. The winding to which the input power is delivered is called the *primary* while the winding which delivers the output to the load circuit is called the *secondary*. These windings are placed over an iron core which is common to each and increases their mutual inductance.

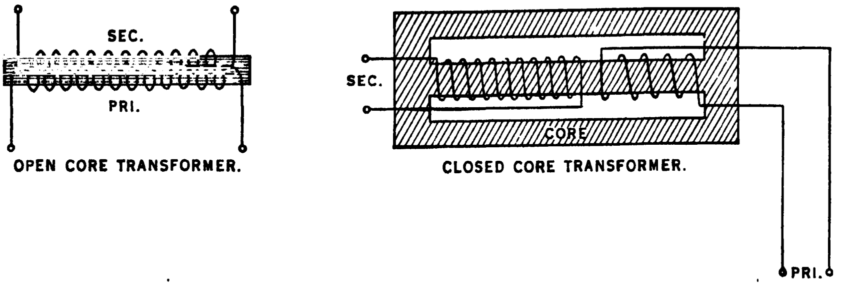


Fig. 1–32. Open- and closed-core transformers.

In some transformers the path of the magnetic flux is partly through the air; such a transformer is called an *open-core* transformer. A transformer in which the magnetic path is entirely through iron is called a *closed-core* transformer. The two types are shown in Figure 1–32. A closed-core transformer has a very small leakage flux. Little flux exists in the air surrounding the core because of the complete path of high permeability offered by the closed core. The primary usually consists of several coils or *"pies"* connected in series and placed directly over the center of the iron core with strips of wood to space the winding from the core in order to provide ventilation.

The secondary also consists of several pies connected in series and mounted over the primary with an insulating material between them.

Transformers having air cores are employed at radio frequencies. The mutual inductance of such windings of an air-core transformer is comparatively small. At low frequencies the efficiency of such transformers is very low. If such transformers were to be employed at high powers, it would become very expensive.

The core of an a-c transformer employed at 60 cycles is constructed of many thin sheets or laminations of silicon steel. By the use of such laminations the losses due to eddy currents are reduced and the transformer can be operated at higher flux densities than one which is not laminated.

1–14b. Ratio of Transformation—If the primary of a step-up transformer has 100 turns and the secondary 1000 turns, the turn ratio is expressed as 1 to 10.

When an e.m.f. of 200 volts is applied to the primary, an e.m.f. of 2000 volts will be induced in the secondary; if the primary current is 50 amp, the secondary current will be 5 amp. From this it can be seen that the larger the number of turns on the secondary as compared to the primary, the larger will be the voltage induced in the secondary. If the voltage is stepped up, the current is reduced or will have a smaller value than that of the primary. The secondary of a step-down transformer, therefore, has fewer turns than the primary, but the wire must be larger.

1–14c. Transformer Operation—The primary circuit of the transformer is connected in series with a source of alternating current which magnetizes the iron core, periodically causing a varying flux to flow through the iron core in accordance with the alternations of current. This variable flux cuts the windings of the secondary, thereby inducing an e.m.f. in this winding and, if the secondary is a closed circuit, current will flow. The current in the secondary will flow in such a direction as to tend to cause a magnetic flux in the core in a direction opposite to the direction of the flux caused by the current flowing in the primary. The flux existing in the iron core must be of sufficient magnitude to induce in the primary winding a back e.m.f. of the same value as the terminal voltage. In order to maintain the flux constant, the current flowing in the primary winding must increase to a value such that the increase in the primary ampere-turns is sufficient to overcome the opposing magnetic effect of the secondary ampere-turns. This reduces the effective inductance of the primary to such a value that sufficient primary current is available in order to maintain a constant flux; when the load is on the secondary the effective inductance of the primary becomes quite small.

1–14d. Losses—The principal losses in a power transformer are of two kinds, the "copper losses" and the "core or iron losses." The copper losses in the primary and secondary windings are equal to the current squared times the resistance. The core losses are of two kinds, the first of which is the *eddy-current* losses due to currents induced in the iron core. Because of the constant reversals of magnetism within the core, considerable energy is expended in changing the positions of the molecules of the iron laminations. This expenditure of energy is known as the *hysteresis* loss. The core losses occur as long as a voltage is applied to the primary and are nearly the same whether or not the secondary is delivering a load current.

1–14e. Cooling—The losses in a transformer represent electrical energy converted into heat. Some means must be provided for dissipating this heat, or the temperature may rise until the transformer is destroyed. Transformers of small size are usually cooled by simply being exposed to the air. The exposed surface of the winding is sufficient to dissipate the heat. Larger transformers are cooled by immersing the windings in oil.

1-15. The Induction Coil—In Section 1-10 it was explained how a varying current passing through a transformer primary induces a voltage in the secondary. There are many radio services where the only primary source of power is low-voltage direct current. In the succeeding chapter it will be explained how this source of power can be converted to higher voltages necessary to operate radio equipment by means of motor generators. Where the primary source of power is a storage battery, a practical use may be made of the induction coil, the fundamental circuit of which is shown in Figure 1-33. The high-voltage alternating current developed in the secondary winding of such a device may be rectified and filtered in the manner explained in chapter 4 and then used as a source of voltage for the operation of radio equipment.

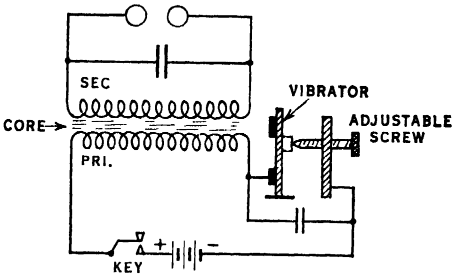


Fig. 1-33. Induction coil.

1-15a. Principle of Operation—In Figure 1-33, the coil is constructed of two windings, primary and secondary, wound on a core of soft laminated iron The primary has few turns of large wire and the secondary many turns of fine wire. Connected in series with the primary is an adjustable vibrator fitted with a soft iron armature so arranged that it will be attracted by the magnetic flux of the iron core. Each time the vibrator is attracted, it is drawn away from a contact through which the primary circuit is completed. Thus, the movement of the vibrator breaks the primary circuit, stopping the primary current. The magnetism of the core therefore collapses, thereby inducing a momentary current surge in the secondary. When the magnetism of the core has died out, the vibrator is released and thereupon moves back, again completing the primary circuit. The core then becomes remagnetized and the process is repeated. This takes place a considerable number of times each second. The frequency of operation depends upon the mass of the vibrator and the stiffness of the spring.

The primary current produces a varying magnetic flux which cut the secondary windings, thereby inducing an e.m.f. in the secondary. The secondary current flows in one direction as the magnetic flux is building up and in the opposite direction as the flux is collapsing. As the current breaks much faster than it makes, the induced e.m.f. is much higher on the break. This is caused by the self-induction of the primary winding.

Two types of vibrators are encountered in radio services; nonsynchronous and synchronous. The operation of a nonsynchronous vibrator is quite similar to that already described, except that two contacts are provided on the vibrator. The action can be followed by referring to Figure 1-34. When the battery circuit is completed, current will flow through the lower half of the transformer primary and the winding of the electromagnet *M*. The armature is attracted by the magnet and contact *A* will touch contact *B*, thereby short-circuiting the magnetic winding; consequently, the armature is released and swings back until contact *A* touches contact *C*. Since the short circuit is now removed from the electromagnet, the core is again magnetized and pulls the armature down until contact *A* again touches contact *B*. Thus, the armature keeps vibrating at its own natural frequency and alternately touches contacts *B* and *C*.

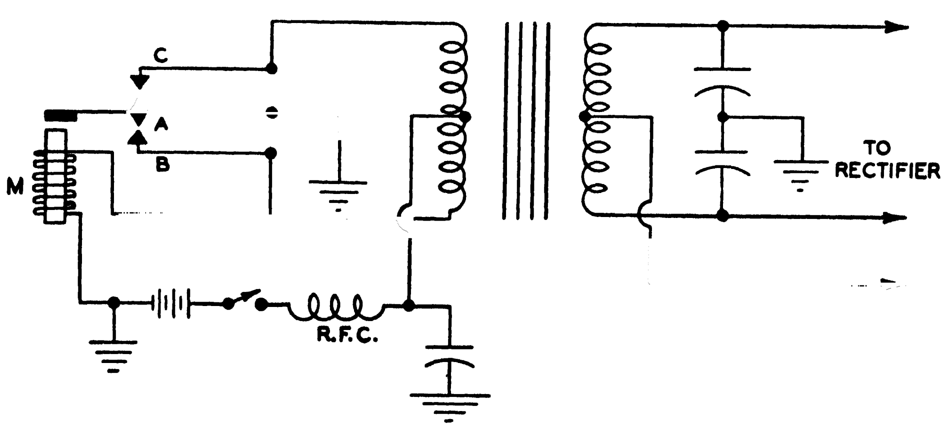


Fig. 1-34. Non-synchronous vibrator circuit.

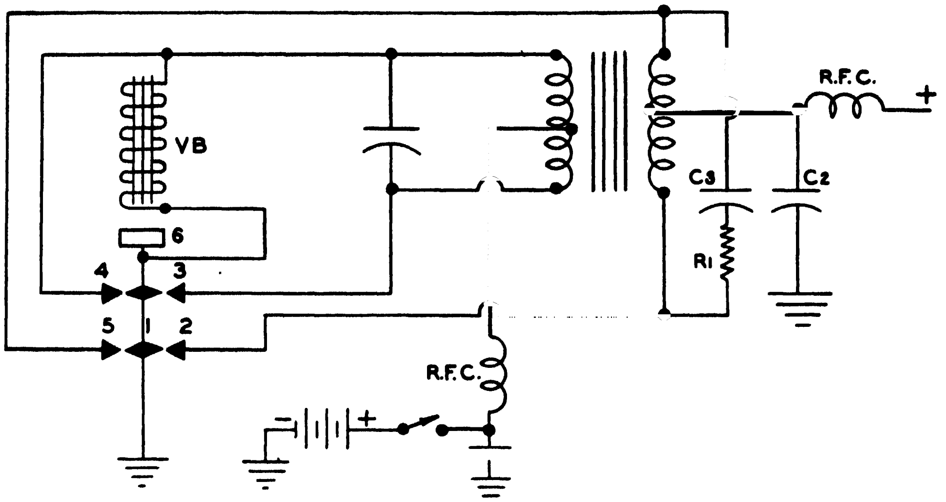


Fig. 1–35. Synchronous vibrator power supply circuit.

When contacts *A* and *B* are closed, the lower half of the primary is connected directly across the battery, which results in the passage of a current from the center tap of the primary downward. When *A* touches *C*, the upper half of the primary is connected across the battery and current will flow from the center tap upward. These two impulses can be considered as alternating curent, although not of sine-wave form, and, consequently, an alternating current will be induced in the secondary of the transformer, when it is rectified, filtered, and used as direct current.

Special precautions must be taken in the design of vibrator systems. When contacts *A* and *B* close, there is a sudden increase of current and a high-voltage peak is induced in the secondary at the moment of contact. The same is true when the other contacts close. This causes sparking at the contact points and, if corrective measures are not taken, excessive sticking, pitting, and burning of the contacts will take place. This is overcome by connecting buffer condensers across the secondary and sometimes across the primary windings. The buffer condensers serve to absorb the sudden charges and thereby improve the waveform of the secondary voltage.

Additional precautions are necessary to prevent interference called "hash" (generated by the vibrator contacts) from interfering with radio reception. This is accomplished by inserting both audio- and radio-frequency choke coils in the plate and filament supply leads.

1–15b. Synchronous Vibrator Power Supplies—The synchronous vibrator not only develops the high voltage required for radio equipment, but also performs the function of rectification, thus obviating the necessity of a rectifier tube. Vibrators are limited, however, to applications where the current requirements are not excessive. Figure 1–35 will assist in explaining the action of a synchronous vibrator. It will be noted that the armature is fitted with an extra set of contacts which are connected to each side of the secondary of the transformer. This permits the current flowing in the secondary to be reversed in synchronism with the reversals of current in the primary. Correct battery polarity is necessary when using the self-rectifying type of vibrator. The current supplied at the output is pulsating d.c. and must be filtered in the usual manner.

Referring to Figure 1–35, the battery voltage is fed through the r-f choke to the center tap of the primary of the transformer. One side of the primary is connected to contact 3 and the other side to contact 4 of the vibrator, *VB*. The coil of *VB* is energized by connection to the ungrounded side of the battery at contact 4, and the armature which is grounded. The contacts of the vibrator interrupt the direct current in the secondary winding, the voltage being stepped up by the turns ratio of the transformer.

Simultaneously, rectifier contacts 2 and 5 rectify the voltage of the secondary by connecting the appropriate side of the secondary winding to ground at the correct instant. This, in effect, results in one half of the secondary winding supplying each alternate half cycle, thereby producing a unidirectional voltage. The rectified voltage is by-passed by condenser C_2 and fed through the r-f choke to the positive terminal of the power pack. Buffer condenser C_3 and resistor R_1 are connected in series across the secondary of the transformer to control surge voltages developed in the circuit. Buffer condenser C_1 is connected to the primary for the same purpose.

1–16. The Wheatstone Bridge—The measurement of all types of impedances—resistive or reactive, inductive or capacitive—utilizing the principle of the Wheatstone bridge is used extensively in the field of radio engineering and communication. The simple Wheatstone bridge permits measuring an unknown resistance in terms of a known resistance. Similarly, a capacitance bridge permits the measurement of an unknown capacitance in terms of a standard or known capacitance. The principle of operation of a Wheatstone bridge can be explained by referring to Figure 1–36.

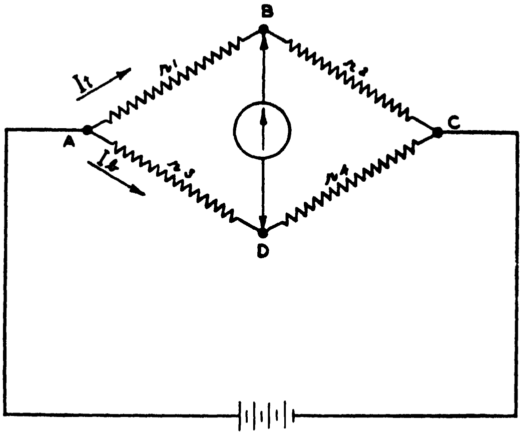


Fig. 1–36. The Wheatstone Bridge.

The theory depends upon the fact that in a branched circuit, as shown in Figure 1–36, the voltage drop from *A* to *C* must be the same over the path *ABC* as it is over the path *ADC*. Consequently, for any point *B* on the upper branch of the circuit *ABC*, there must be some point *D* on the lower branch, such that there will be no difference of potential between point *D* and point *B*. Point *D* can be found by connecting one terminal of a current-indicating device to point *B* and moving the other terminal of the indicator along the lower branch until the deflection of the meter pointer falls to zero. This means that there is no current flowing through the indicator and hence no potential difference exists between points *B* and *D*. When points *B* and *D* have been located in this manner, it can be shown that there is a definite relation between the resistance of the four arms of the circuit.

If I_t is the current through the top branch and I_b is the current through the bottom branch, then the voltage drop across R_1 is r_1I_t and is equal to r_3I_b, the voltage drop between *A* and *D*.

Therefore,

$$r_1I_t = r_3I_b$$

$$\frac{r_1}{r_3} = \frac{I_b}{I_t}$$

Likewise

$$r_2I_t = r_4I_b$$

$$\frac{r_2}{r_4} = \frac{I_b}{I_t}$$

So

$$\frac{r_1}{r_3} = \frac{r_2}{r_4}$$

and

$$r_1r_4 = r_3r_2$$

then

$$r_4 = r_3\frac{r_2}{r_1}$$

Therefore, it can be seen that if the value of three of the resistances are known, the fourth (r_4) can be calculated. In practice the unknown resistance becomes one arm of the bridge circuit and the known values of resistance are adjusted until the bridge is balanced, as shown by no deflection on the indicating device. In general, the null method of obtaining a balance is used; that is, the voltage which is introduced through the generator terminal connections is reduced to zero between the two opposite points on the bridge.

Special precautions must be taken in the design and connections of the bridge and associated equipment, so that stray currents are not introduced from extraneous sources.

There are several modifications of the Wheatstone bridge which bear the names of those who developed them for various kinds of measurements. Among these will be found Maxwell, Hay, Owen, and Schering types of bridge.

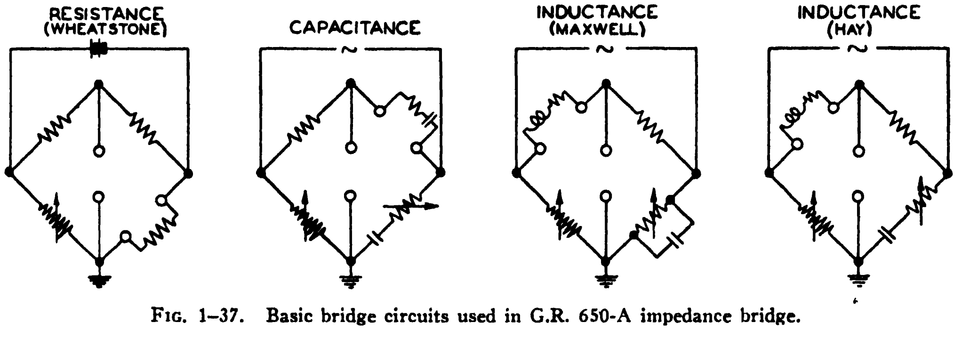


Fig. 1–37. Basic bridge circuits used in G.R. 650-A impedance bridge.

FIG. 1–38. General Radio type 650-A impedance bridge.

Figure 1–37 shows a schematic diagram of the circuits used in the General Radio type 650-A impedance bridge. This bridge is designed to measure the inductance of coils, the capacitance and power factor of condensers and the d-c resistance of all types of resistors. In the laboratory, it is extremely useful for measuring the circuit constants in experimental equipment, testing preliminary samples, and identifying unlabeled parts. In the shop and on the test bench, it has many applications in routine testing and trouble shooting.

The type 650-A impedance bridge is a conventional 4-arm bridge. It is self-contained, including standards, batteries, and tone source, and is direct-reading over wide ranges of d-c resistance, a-c resistance at 1000 cycles, capacitance and dissipation factor $\left(D = \frac{R}{X}\right)$ at 1000 cycles, and inductance and storage factor $\left(Q = \frac{X}{R}\right)$ at 1000 cycles.

Results are read directly from dials having approximately logarithmic scales (Figure 1–38). The position of the decimal point and the electrical unit in terms of which the measurement is made are indicated by the positions of two selector switches.

Resistance is measured in terms of a standard resistance arm; inductance and capacitance are measured in terms of mica condenser standards. Power is supplied from dry cells, which operate a 1000-cycle hummer for a-c measurements. The bridge may also be used with an external generator of any audio frequency. The detector for d-c measurements is a built-in galvanometer. For 1000-cycle measurements, head telephones are used.

CHAPTER 2

MOTORS AND GENERATORS

The motor and generator are machines that convert energy from one form to another. A generator converts mechanical energy into electrical energy; conversely, a motor converts electrical energy into mechanical energy. The term "dynamo," a shortening of "dynamoelectric machine," refers to either a motor or generator.

Motors and generators consist of the same basic elements: a strong magnetic field and current-carrying conductors which move in, or are otherwise affected by, the magnetic field. A motor will operate as a generator if mechanical power is applied; as a matter of fact, there is little difference in construction between d-c motors and d-c generators. A-c machines have greater structural differences but, in general, will operate as either motors or generators.

2–1. The Alternating-current Generator—The simplest form of alternating-current generator is made of a loop of wire rotating in a uniform magnetic field as illustrated in Figure 2–1. In order to make electrical contact to each end of the loop during rotation, circular metal rings, known as *slip rings* or *collector rings*, are employed. Brushes pressing against these rings make continuous contact as the loop is rotated.

If a load resistor and a current-indicating device are connected across the brushes and the loop of wire rotated, it will be observed that a current flows through the external circuit. This current is a result of the conductor cutting through the magnetic field, and the strength of the current will be found to change from instant to instant as the position of the loop changes. In addition, it will be found that the current is alternating, that is, it changes its direction every 180° of coil rotation.

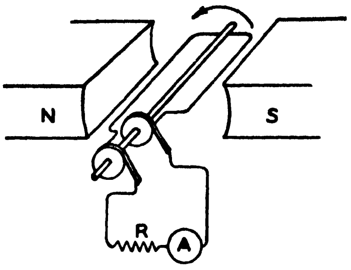


FIG. 2–1. An elementary a-c generator consists of a loop of wire rotating in a magnetic field.

Figure 2–2 illustrates how the generated current varies through one complete rotation of the loop. In (*A*) the loop is in a vertical plane and is moving parallel to the magnetic lines of force; therefore, no lines are being cut and the generated voltage is zero. As the loop rotates in a counterclockwise direction, the conductors start cutting through the

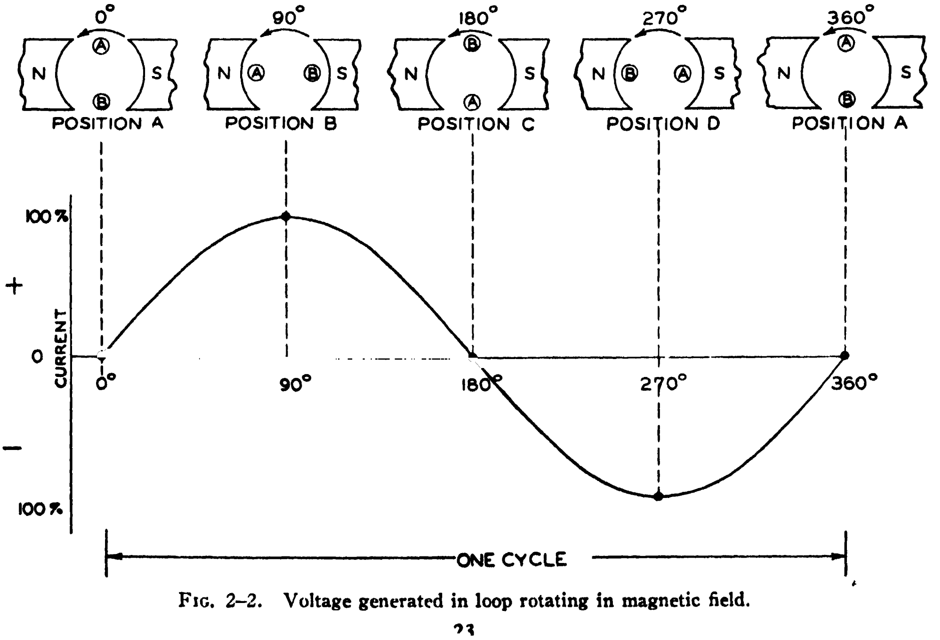


FIG. 2–2. Voltage generated in loop rotating in magnetic field.

magnetic lines of force and a current increasing in strength is induced in the conductors. When position (*B*) is reached, the conductors are in a horizontal plane, the maximum number of magnetic lines of force are being cut, and the generated current is at a maximum. Between (*B*) and (*C*), the current diminishes, reaching zero when (*C*) is reached. This position corresponds with (*A*); however, the sides of the loop are now reversed as the loop has passed through only 180° of rotation. As rotation continues toward position (*D*), current again flows, but this time in the opposite direction. The current reaches a maximum at position (*D*) and then decreases, reaching zero again when the position corresponding to (*A*) is again reached. This sequence of events constitutes one cycle; the first 180° of rotation is known as the positive half cycle; the last 180° of rotation, the negative half cycle.

In small a-c generators, such as the hand-operated telephone magneto used for supplying ringing current in portable telephone equipment, the magnetic field is often supplied by a U-shaped permanent magnet. In larger machines, field coils carrying a strong direct current are used to provide the magnetic field. When field coils are used, a variable resistance called a field rheostat is provided to permit adjustment of the strength of the field and thereby the strength of the generated voltage. The general arrangement is illustrated in Figure 2-3

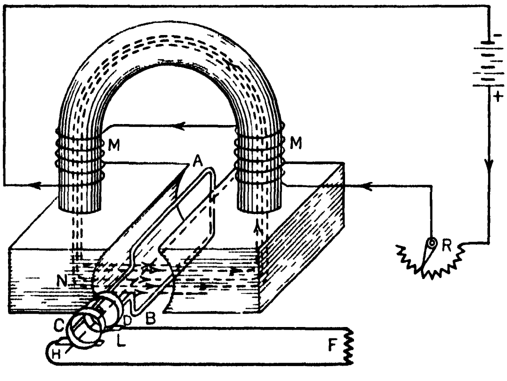


FIG. 2-3. An elementary a-c generator showing external circuits.

The a-c generator of Figure 2-3 is known as the revolving-armature alternator inasmuch as the armature is the element that rotates. This type of machine is not frequently encountered in practice, having been supplanted to a large extent by the revolving-field type of generator, Figure 2-4. The revolving-field machine has several advantages over the revolving-armature machine, the main advantage being that the slip rings are required to carry only the relatively small d-c exciting power to the revolving-field since the much higher output from the stationary armature can be connected without the use of moving contacts. The exciting power for the rotating field is commonly obtained from a small d-c generator known as an exciter.

FIG. 2-4. The revolving field type alternator. (Courtesy Westinghouse Electric and Manufacturing Co.)

2-1a. Inductor Alternator—An inductor alternator has been employed in radio work extensively in the past and is still encountered upon occasion. In this type of machine both the armature and the field are stationary; the rotating element, known as the inductor, is a disc-shaped mass of iron in which a large number of teeth or pole pieces have been cut. The general arrangement is shown in Figure 2-5. A considerable gap separates the field and armature pole pieces. In this gap is the iron inductor *I*, which is free to revolve on its shaft.

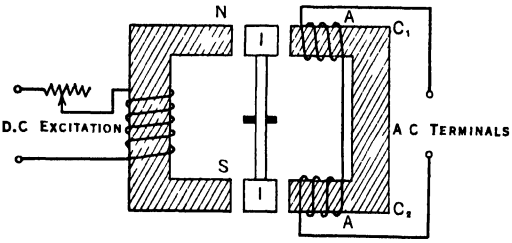


FIG. 2-5. Basic construction of inductor type of alternator.

When the teeth or pole pieces of the armature are in the position shown, a magnetic circuit of high permeability exists through the field and armature cores. When the inductor has rotated a few degrees and an air gap exists across the pole pieces, a magnetic circuit of low permeability results. The armature windings *AA* are subjected, therefore, to a magnetic field of varying intensity, and an alternating current is induced in these windings. This current flows in one direction while the magnetic field is increasing and in the opposite direction when it is decreasing.

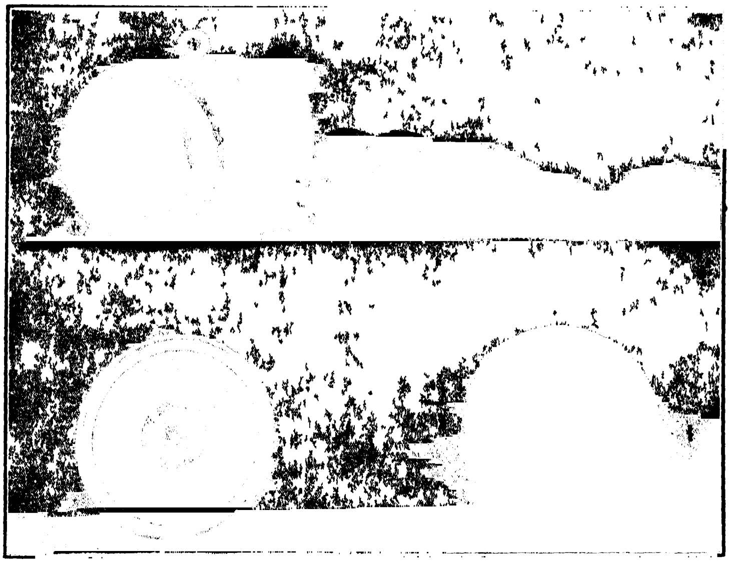


FIG. 2-6. Disassembled view of Crocker-Wheeler 2 kw motor-generator with inductor type of alternator

Inductor types of alternators have been constructed to generate frequencies as high as 200,000 cycles per second This high frequency is obtained by having 200,000 inductor teeth pass a given point every second The result can be obtained only by having very many teeth on the rotor and then driving the rotor at very high speed. Inductor alternators have also been employed to generate a frequency in the order of 500 cycles per second These units were used extensively in connection with spark and I C W transmitters Such a unit is illustrated in Figure 2-6 A recent use of this type of generator is as a tone generator in electric organs and similar devices

2-1b. Determination of Frequency—The frequency of an alternator may be determined in the following manner:

$$f = \frac{n \times s}{120}$$

where f = frequency in cycles per second
n = number of field poles
s = speed of armature in revolutions per minute

In commercial practice, the frequency of the generator is increased by increasing the speed of the armature since the field poles are fixed

The voltage of the generator may be increased by increasing the speed of the armature or by increasing the strength of the magnetic field. Generally, the latter procedure is employed because increasing the speed of the armature will increase the frequency whereas increasing the field strength will make no change in frequency.

2-2. Direct-current Generators—As pointed out in the preceding paragraphs, the current induced in the armature windings of a generator is always alternating. If direct current is required, it is necessary to provide a means of rectifying this alternating current. A simple mechanical switching device, known as a commutator, is employed for this purpose. The commutator is built on to the armature of the machine in the manner illustrated in Figure 2-7.

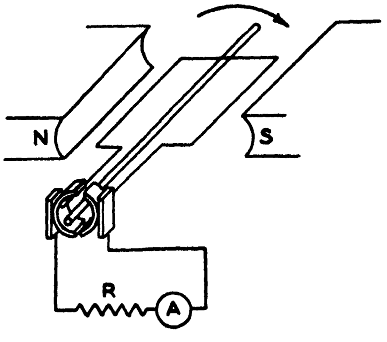


FIG. 2-7. Elementary d-c generator The commutator is a mechanical switching device which rectifies the a c. induced in the loop.

In order to explain the operation of the commutator, let us assume that the loop of wire is revolving in a uniform magnetic field and that an alternating current is being induced in the wire in the same manner as described in Section 2-1. Each end of the loop is connected to a half cylinder of metal, the two half cylinders forming a simple commutator. A pair of brushes rest against this commutator for the purpose of collecting the generated power. As the loop rotates, the connection to the external circuit is reversed each half cycle with the result that the generated half cycles always flow through the external circuit in the same direction, Figure 2–8. The brushes are so positioned that the transfer from one metal segment to the next is made when the current in the armature is zero and about to reverse.

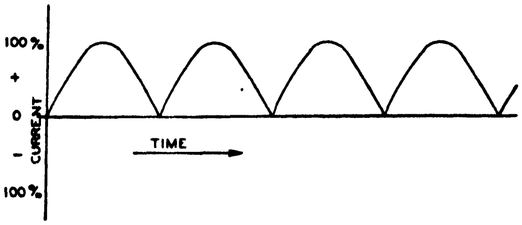


Fig. 2–8. Waveform of current supplied to external circuit by elementary d-c generator of Fig. 2–7.

The output of the simple d-c generator described is known as a pulsating direct current because of its waveform, Figure 2–8. In commercial generators many armature coils are employed, each connected to its own set of commutator segments, with the result that the generated currents overlap until the resultant current is of a substantially constant value. The slight variations present are known as "ripple."

The commutator of such a machine consists of bars of copper, slightly wedge-shaped, separated by thin insulating sheets of mica, the whole assembled in the form of a cylinder held together by strong end clamp rings. The segments are insulated from the clamps by suitably shaped rings, usually of molded mica insulation. Connections leading to the armature conductors are soldered into slots in the segments, which commonly have lugs or risers for the purpose, extending upward at the end toward the armature.

D-c generators may be so connected that excitation is secured from their own generated armature current, no exciting current from an external source being required. The field windings may consist of many turns of small-size wire carrying a small current, or a few turns of large size wire carrying a large current, the same flux strength being possible in either case. In many generators, both types of winding are employed to obtain the required characteristics. D-c dynamos are classified according to the type of field winding employed and the method by which the field winding is excited. In general, d-c machines may be grouped into the two following major classifications:

1. Externally excited machines
2. Self-excited machines

D-c machines may be further classified according to the actual circuit arrangement used as follows:

1. Shunt-wound machines
2. Series-wound machines
3. Compound-wound machines

Each of these latter classifications are discussed in the following paragraphs.

2–2a. The Shunt-wound D-c Generator—The circuit arrangement of the shunt-wound d-c generator is shown in Figure 2–9. As can be seen, the field winding, together with a series resistor known as a field rheostat, are connected directly across the armature terminals. Therefore, the full output voltage of the armature can be applied across this field winding.

Shunt-wound fields are wound with many turns of relatively small-size wire and their resistance therefore is high compared with the resistance of the armature winding. Hence, only a small portion of the current generated by the machine flows through the field windings. The field current can be regulated by a field rheostat.

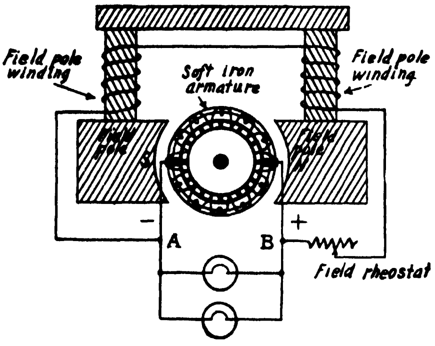


Fig. 2–9. Circuit of shunt-wound generator.

When the armature of the machine is started, it has to depend upon the small residual magnetism of the field poles to generate its initial current. Residual magnetism, as already explained, is the small amount of magnetism retained by soft iron after once having been magnetized.

As the armature rotates, the residual lines of force cut the windings of the armature, thereby generating a small current that flows through the shunt field windings and increases the number of lines of force cutting the armature coils. This induces a stronger current in the armature windings that continually adds to the strength of the field until the normal voltage of the generator is established. The complete process requires only a few seconds. After the generator has attained its normal speed, the voltage across its terminals may be raised or lowered by adjustment of the field rheostat. Increasing the resistance decreases the generator terminal voltage. Decreasing the resistance allows more current to flow in the field windings and increases the generator terminal voltage.

2–2b. The Series-wound D-c Generator—The circuit arrangement of the series-wound d-c generator is shown in Figure 2–10. As can be seen, the field windings are connected directly in series with the armature and therefore must carry all current

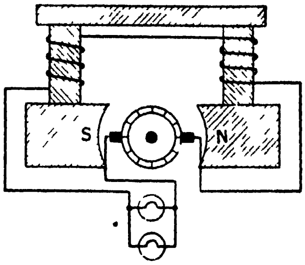


Fig. 2–10. Circuit of series-wound generator.

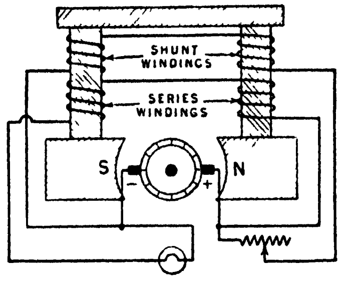


Fig. 2–11. Circuit of compound-wound generator.

delivered by the machine to the load. The field winding therefore must employ large-size conductors to handle large currents without overheating.

The necessary ampere-turns are obtained by having a large number of amperes and comparatively few turns of wire. In starting, the current passing through the field windings strengthens the weak residual magnetism field and the normal voltage of the generator is soon attained.

2-2c. The Compound-wound D-c Generator—The field poles of a compound-wound machine, Figure 2-11, are equipped with two sets of field coils—one set of windings being series-connected, the other set being shunt-connected. The two sets of windings are usually connected in such a manner that they aid each other in setting up the magnetic field, and under these conditions the compound arrangement is said to be *cumulative*. At times, the two sets of windings are arranged to oppose each other, this arrangement being known as ***differential.***

When the shunt field is connected directly across the armature of the machine, Figure 2-12a, the arrangement is known as a short shunt; if the shunt field is connected after the series field, Figure 2-12b, it is called a long shunt.

The compound wound machine has the advantage that the generated voltage can be maintained quite constant with varying loads as described below.

2-2d. Characteristics of Shunt-, Series- and Compound-wound Generators—When shunt excitation is used the potential difference at the armature terminals is reduced if the external load is increased. The effect of the reduced terminal voltage is to reduce the current through the field windings, resulting in a weakened field. With increased load the armature current increases as the shunt field current decreases; hence the terminal voltage falls off considerably.

With series excitation the condition is very different. When there is no load on the generator, only the residual magnetism of the pole pieces is available, and the terminal voltage is consequently very small. As the load increases larger values of current flow through the field windings, permitting a greater e.m.f. to be generated. The greater the current taken by the external circuit, the greater will be the voltage.

The compound-wound generator produces a more constant voltage on circuits of varying load than is possible with a generator employing either shunt or series excitation. As the external load of a shunt generator is increased, the potential difference at the armature terminals will fall, but in the case of the compound-wound generator, this fall of voltage is counteracted by the series winding, the current which flows in it increasing with load and causing the terminal voltage to rise. The number of turns of each winding and the relative strength of current are proportioned so that a practically constant voltage is maintained under varying load.

Each type of generator has its special applications. For instance, the exciter for an a-c generator of a radio transmitter can be a shunt generator because the load varies very little. Incandescent

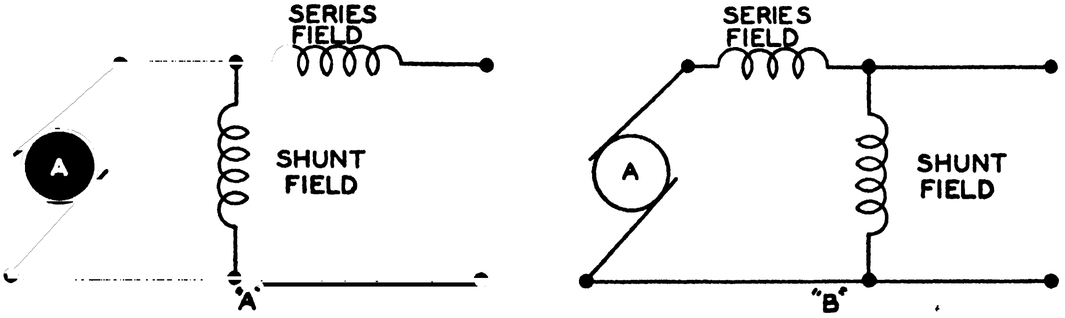


Fig. 2–12. Compound-wound generators; "A" short shunt, "B" long shunt.

lamps require a steady voltage that is not changed when some of them are turned on or off. A compound generator meets this requirement.

2-2e. Voltage Regulation—The voltage regulation of a generator is an expression of the relation between the voltage with no load and full load. It may be found in the following manner:

$$\text{Regulation} = \frac{E_{nl} - E_{fl}}{E_{fl}} \times 100$$

where E_{nl} = voltage with no load
E_{fl} = voltage with full load

Regulation is expressed in per cent. A low value indicates that the voltage remains very nearly constant as the load varies. A high value means that the voltage drops considerably on load and the machine therefore has poor regulation.

Example: Consider a transmitter whose a-c generator no-load voltage is 300 volts. The key is closed and the voltage drops to 270 volts.

Solution: Substituting in the above formula

$$\left(\frac{300 - 270}{270}\right) \times 100 = 11\% \text{ (approx.)}$$

2-2f. Reversal of Polarity of Generator—It sometimes happens, especially on ships' generators, that, while batteries are on charge, the generator is stopped without first removing the load from the machine. Unless the charging circuit is protected by circuit breakers, the battery will immediately start to discharge through the generator resulting in a reversal of the residual magnetism. When the machine is again started, the reversed residual magnetism reverses the polarity of the generator brushes, thus reversing the direction of the field current and making it agree with the new direction of the residual magnetism. This will allow the generator to build up, but the polarity will be reversed. The residual magnetism can be again reversed so that the generator will have its normal polarity by sending a current from another generator or a battery through the field in the proper direction. This is accomplished by connecting the positive terminal of the battery to what is now the new positive terminal of the generator and the negative of the battery to the negative of the generator. The brushes should be lifted or removed during this operation. A battery of 6 to 12 volts will sometimes accomplish the correct result. If the reversal does not take place immediately, the battery should remain connected to the fields for an hour or two.

2-2g. Ground Indicators—Ground indicators, consisting of two lamps in series with the midpoint grounded, are sometimes installed on switchboards. Figure 2-13 shows the connections of such indicators. Normally the two lamps in series will light dimly. Should a ground occur on either leg of the circuit one of the lamps will light to full brilliancy. For instance, assume the positive leg of the circuit in Figure 2-13 becomes grounded; this will short-circuit lamp number 2, and lamp number 1 would then be directly connected across the generator terminals and would be taking the full voltage.

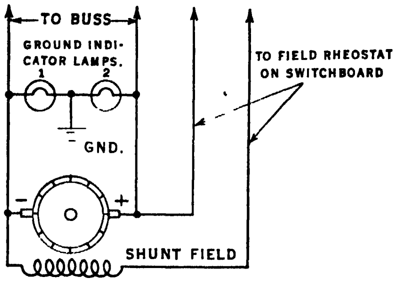


FIG. 2-13. Circuit of ground indicator on d-c generator.

2-3. Direct-current Motors—There is no essential difference between the d-c generator and d-c motor. With the exception of minor differences to adapt them to meet best their specific requirements, the structures of both are substantially the same. However, their functions are reversed, the motor converting electrical energy into mechanical energy. D-c motors, like d-c generators, may be classified into three types according to their field arrangement: (1) shunt-wound, (2) series-wound, and (3) compound-wound.

The fundamental operating principle of a motor may be explained in the following manner. When a current-carrying conductor is placed in a magnetic field, there is present a force that tends to push the conductor across the field. The conductor will move in a direction at right angles both to the direction of the field and to the direction of the current. For example, if the plane of a coil lying between the poles of a magnet is parallel to a magnetic field, and a current is passed through the coil, it will tend to turn or take up a position at a right angle to the magnetic field. If the current is reversed when it has reached this position, the coil will continue to turn.

2-3a. The Shunt-wound D-c Motor—The operation of the motor can be explained by the diagram in Figure 2-14 which shows the circuit arrangement of the shunt-wound d-c motor. The current flowing through the armature windings from the battery is in such a direction that the lower half of the armature coils is magnetized and has a South pole whereas the upper half has a North pole. The upper half will then be attracted by the S field pole and repelled by the N field pole. The lower half will be attracted by the N field pole and repelled by the S field pole.

The action will be continuous, because, as the top of the armature moves toward the S field, the commutator acts to maintain the flow of current in the same direction as before, consequently the upper half of the armature is always a N pole and the bottom a S pole. Thus the armature is made to revolve when supplied with current.

Compare the circuit of the shunt-wound motor of Figure 2–14 and the shunt-wound generator of Figure 2–9. They are fundamentally the same. If a shunt-wound generator was charging batteries and the driving engine was shut off, the generator would continue running, providing the battery circuit was large enough and had no circuit breakers.

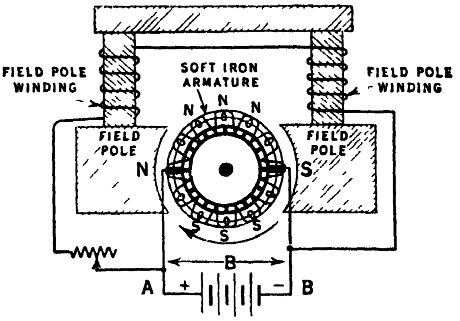


Fig. 2–14. Circuit of d-c shunt motor.

The ammeter in such a circuit would indicate a current in the opposite direction, as the battery would be discharging and driving the generator as a motor, exactly as described in the previous paragraph.

Direction of Rotation. If the connections from the battery were reversed at points *A* and *B* in Figure 2–14, it would have no effect on the direction of rotation. The armature would still continue to rotate in the direction of the arrow. Reversing the connections from the battery would reverse the polarity of the magnetic flux in both the armature and the field poles. The N field pole would become a S field pole and S field pole would become a N field pole. Likewise the armature S pole would become a N pole and the S pole of the armature a N pole. The same power of attraction and repulsion between like and unlike poles would result with no change in direction of rotation. In order to change the direction of rotation the *flow of current must be changed in either the armature or field coils, but not in both.* For example: In Figure 2–14 reverse the field poles only. The N pole is now a S pole and the S pole a N pole. The direction of armature current has not been changed, therefore the upper half is still a N pole and lower half a S pole. The N pole of the armature being attracted by the new S pole, rotation begins opposite to the arrow or counterclockwise, where before, as shown by the arrow, the direction of rotation was clockwise. The same thing would result if the armature windings had been reversed instead of the field windings. The general practice is to reverse the current in the armature rather than in the fields.

Counter Electromotive Force. As soon as the armature of a motor starts to rotate, a voltage is induced in the armature windings of such polarity as to oppose the voltage that started the motion. This opposing voltage is known as counter electromotive force and governs the speed of a motor. The value of counter e.m.f. is proportional to the speed of the armature, the number of armature wires and the strength of the magnetic field. The counter e.m.f. can never be as great as the line voltage. If a load is placed on the motor the speed falls off and consequently the value of the counter e.m.f. falls off. The current in the armature is increased as the counter e.m.f. falls off and the motor automatically regains speed of sufficient value to drive the load.

The field magnets of the shunt-wound motor are always of the same strength, regardless of the load, because the current flowing through them depends only on the line voltage and the resistance of the field coils. It is entirely independent of the current in the armature. Thus the speed of a motor supplied with direct current at constant voltage varies directly with the counter e.m.f. and, in any given machine, the stronger the field the slower will be the speed of the armature. The strength of the field can be regulated by a variable resistance, or rheostat, in series with the field windings. If the resistance of the field rheostat is *decreased,* more current flows through the field windings, thus increasing the field strength; consequently the *speed of the motor is reduced.* If the resistance of the field rheostat is *increased,* the magnetic field is weakened, resulting in an increased speed of the motor up to a certain point, or until the increased speed of the armature increases the counter e.m.f. to such an extent as to cut down the armature current. If the field rheostat accidently burns out or should an open circuit occur in the shunt field the armature will develop terrific speed. The centrifugal force may become great enough to burst the windings of the armature, therefore requiring expensive repairs to the machine. If, upon starting, the circuit breakers trip, fuses blow, or excessive current is drawn, the machine should be stopped at once and investigation made to determine if the field circuit is properly connected.

From the above it can be seen that the advantage of a shunt wound motor is that it is self-regulating and maintains a fairly constant speed under varying load.

Starting Resistance. The resistance of a motor armature is small. Should full line voltage be applied directly to the armature terminals upon starting, excessive current would flow which may injure the commutator or burn out the armature windings. The counter e.m.f. developed after ro-

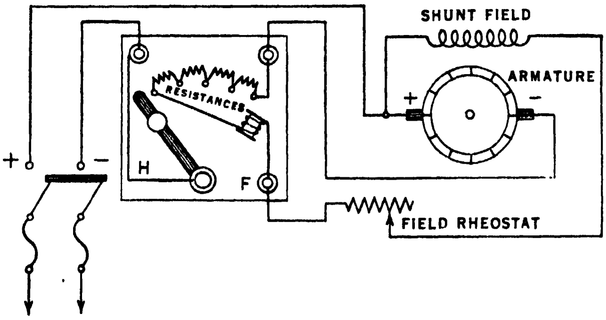


FIG. 2–15. Hand starting box connected to shunt-wound motor.

tation has started keeps the armature current from becoming excessive. When the motor is first connected to the line, it is not rotating and there is no counter e.m.f. Some means must therefore be employed to limit the armature current until the machine has attained sufficient speed to generate the required counter e.m.f. This is accomplished by a variable resistance connected in series with the armature, the value of which is gradually reduced as the motor gains speed. A device of this type is called a starter. A circuit diagram of a shunt-wound motor with a hand-operated starting box is shown in Figure 2–15.

The action of a typical hand starter is as follows: As handle *H* reaches the contact on the first resistor, *R*, the armature circuit is completed with all the starting resistors in series, thus limiting the armature current to a low value, and the motor starts slowly. The motor field circuit is completed through the windings of magnet *M* and the field rheostat. As the handle is moved toward the full running position, the motor gains speed, and the value of counter e.m.f. is increased. When in full running position with all the resistance of the starting box cut out, the motor is generating a counter e.m.f. of such a value as to permit the full line voltage to be applied directly to the terminals of the armature. No change has been made in the strength of the field by the operation of the starter. The holding magnet *M* holds the handle in the full running position unless demagnetized by interruption of the d-c supply or an open in the field circuit. Should the d-c line be interrupted, the handle automatically returns to the off position, requiring the motor to be restarted in the normal manner. Should the handle fail to fall back, excessive armature current would flow when the line voltage was restored, resulting in damage to the machine as explained previously. Should the field develop an open circuit, the holding magnet again would be demagnetized, thus releasing the starting handle and preventing the motor from attaining excessive speed.

If a motor is started too slowly the starting resistors may overheat and burn out. If started too rapidly, excessive armature current will flow, opening line fuses or tripping the circuit breakers.

2–3b. The Series-wound D-c Motor—As in the case of the d-c generator, the field windings of a d-c motor may be wound with large-size wire and connected in series with the armature. In this case, the same current flows through both armature and field windings. This arrangement is known as the series-wound d-c motor.

The operating characteristics of a series-wound motor are considerably different from those of a shunt-wound motor. They do not maintain a constant speed but run much more slowly when heavily loaded. At the lower speeds they develop a powerful torque, and are used to advantage as the starting motors on street cars where high turning effort is required. They are of little value in radio work where a constant-speed motor is required.

2–3c. The Compound-wound D-c Motor—Compound-wound fields (Section 2–2c) are commonly employed in d-c motors to combine in a single machine the high starting torque characteristic of the series-would motor and the good speed regulation characteristic of the shunt-wound motor. The compound connection can be made in a manner that the series-winding aids the shunt-winding, this arrangement being known as *cumulative,* or in a

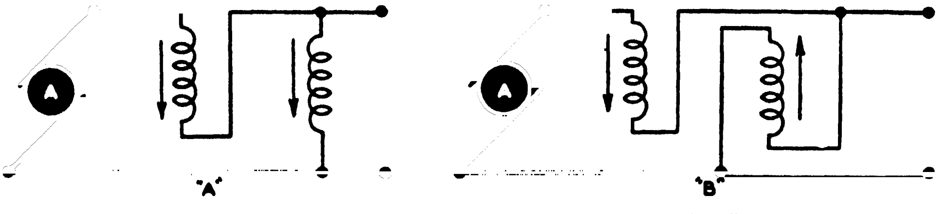


FIG. 2–16. The compound-wound motor; "A" cumulative, "B" differential.

manner that the series-winding opposes the shunt winding, this arrangement being known as *differential.* Compound-wound motors have the advantage that the load can be completely removed without danger to the motor as the speed will not become excessive.

The cumulative compound-wound motor, Figure 2-16A, is characterized by speed variations greater than the shunt-wound motor. The actual change in speed is governed by the relative strength of the series field. The differential compound motor, Figure 2-16B, is characterized by better speed regulation than the shunt-wound motor but has the disadvantage that the speed becomes unstable when the the machine is heavily loaded. For this reason, the differential arrangement is not often employed.

The speed of compound-wound d-c motors is controlled by a field rheostat connected in series with the shunt field winding.

2-4. Automatic Starters—It is often desirable to install the motor generator of a radio transmitter at a point remote from the radio room, in order that the noise from its operation will not interfere with the reception of radio signals. In instances of this kind, automatic starters are employed. They are controlled from a distant point by pressing a button or closing a switch. The automatic starter solenoid and resistances sometimes are a part of the transmitter in the operating room and are controlled by a start-stop switch mounted close to the antenna send-receive switch on the operating table.

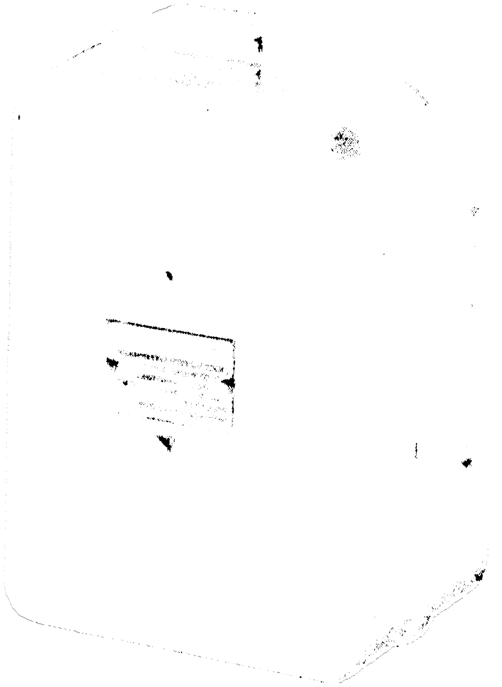


FIG. 2-17. General Electric automatic starter.

In general, automatic starters operate in such a manner that resistance steps are cut out progressively as the speed of the motor accelerates.

2-4a. General Electric Automatic Starter—Figure 2-17 shows a photograph of the General Electric automatic starter employed with RMCA radiotelegraph transmitters described in Chapter 13. This magnetic starter incorporates an escapement time-delay mechanism driven through an overrunning clutch so that two resistors in series with the armature are cut out progressively as the armature gains speed and develops sufficient counter e.m.f. to permit application of the full line voltage. Figure 2-18 shows the step-by-step operation of this starter. The timing mechanism, which can be adjusted to give a total accelerating period of from 1 to 6 seconds, consists of simple, accurate, easily adjusted pendulum arrangement similar to the escapement of a clock.

2-5. Alternating-current Motors

The Induction Motor. It has been explained how a current flowing through a coil produces a magnetic field. If a set of coils is arranged in the form of a two-phase or three-phase field and connected to an alternating current having two or more phases, it will be observed that a compass needle placed within the field will spin around and will continue to do so as long as the coils are energized. The effect is as if the needle of the compass were under the magnetic influence of a magnet with its poles sliding along the face of the field.

The action of an induction motor can be explained by comparing it to a transformer in which the stator is the primary and the rotor is the secondary. Both have poles and these tend to repel each other. Because the stator field revolves, it drives the rotor before it at a speed which is almost the same as the rotating field at no load but which is slightly reduced by any load applied to the motor shaft, or any resistance put into the secondary (rotor circuit).

The speed of the rotor of an induction motor depends upon the construction of the stator and the frequency of the alternating current. In the simplest form there is no connection between rotor and external circuit. However, some types of induction motors have the rotor fitted with slip rings to provide connection to an external resistance which controls the speed of the machine. This is usually accomplished by providing the rotor with a three-phase Y-connected winding and connecting a variable resistance in series with each phase, as shown in Figure 2-21. By means of the three-pronged arm, the resistance in series with each phase of the rotor winding can be varied from the full amount to zero, thus varying the speed from minimum to full speed.

The terms "squirrel cage" and "wound" rotor are often used to describe rotors. The first refers to the simple type with conductors of plain bars of metal and no slip rings or other moving contacts;

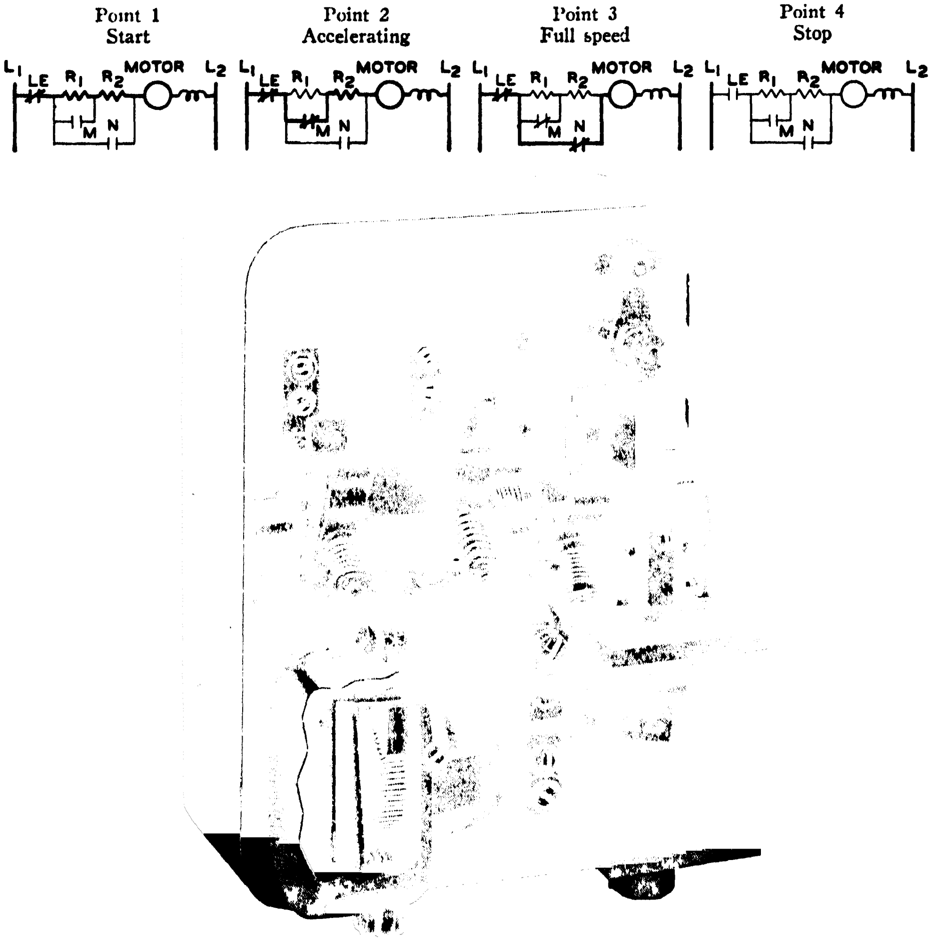


Fig. 2-18 Step-by-step operation of the General Electric automatic starter.

the second refers to the type having coils like the armature of a d-c machine and fitted with slip rings.

Induction motors are polyphase machines, that is, two-phase or three-phase current is required for their operation. They cannot be started on single-phase current but will operate on it if started in some other manner. One way of starting an induction motor is by the use of a "phase splitter." The armature in this case has two sets of coils, one having more inductance than the other. Because of a difference in reactance of the two coils, the currents flowing through each are not in phase. The motor starts then as a two-phase machine. After it gets

Fig. 2-19. Stator of induction motor. (Courtesy General Electric)

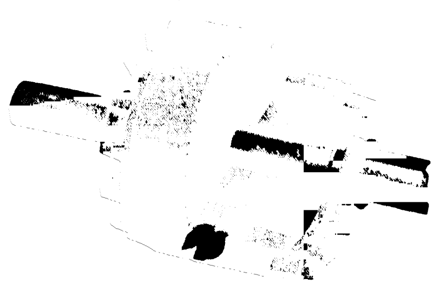


Fig. 2-20. Squirrel-cage rotor of induction motor. (Courtesy General Electric.)

up to speed, the starting winding is disconnected either by a switch having a starting and running position or by an automatic centrifugal cut-out in the motor.

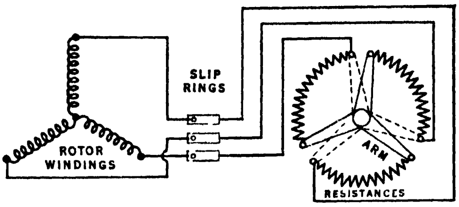


FIG. 2-21. Speed control connection of three-phase induction motor.

2-6. Motor-generators—Direct current is usually the only available power on ships. In order to operate the power transformer of a transmitter, it is necessary to use alternating current. The plates of vacuum tubes require d-c voltages considerably higher than those provided by the ship's generators. When electric current is available, but not in the form needed, a change can easily be made by a motor-generator. In the case of shipboard vacuum tube transmitters, the combination may consist of a d-c motor and a d-c generator which provides d-c voltages considerably higher than those available from the ship's generator. In broadcasting stations, the combination may be an a-c motor coupled to a d-c generator. Such machines usually have four bearings—two for the motor armature and two for the generator armature. In the case of a shipboard installation, the field of the generator is excited from the d-c ship's supply. Field excitation is controlled by a generator field rheostat. Figure 2-23 shows the general construction of a motor-generator.

2-7. Rotary, or Synchronous Converters—It has already been pointed out that the current generated in the armature of a d-c generator is alternating. If, therefore, slip rings were installed on the armature of a d-c generator in addition to the commutator, it would be possible to obtain both d.c. and a.c. from the same machine. Since this armature is able to supply either a.c. or d.c. from the same winding, one naturally suspects that it might be possible to *feed in* a.c. at one end and take off d.c. at the other. This is possible and such a machine is called a *rotary converter.*

The rotary converter shown in Figure 2-24, has a single winding on one armature for both alternating and direct current. Direct current from an external source enters the armature *A* through brushes *B*1 and *B*2 and also flows through shunt field *SF*, causing the armature to revolve in the usual way. Taps are taken off the commutator segments underneath the brushes and are connected to collector rings *CR* on the opposite end of the shaft, the circuit continuing through the primary of an a-c transformer, *T*. The a-c voltage will be maximum when taps to the collector rings are underneath the brushes, and minimum when midway between the brushes. The a-c voltage of the converter may be increased by increasing the speed of the armature, but the frequency will increase simultaneously. When such a machine is run as a d-c motor and used to supply alternating current, it is referred to as an "inverted rotary converter."

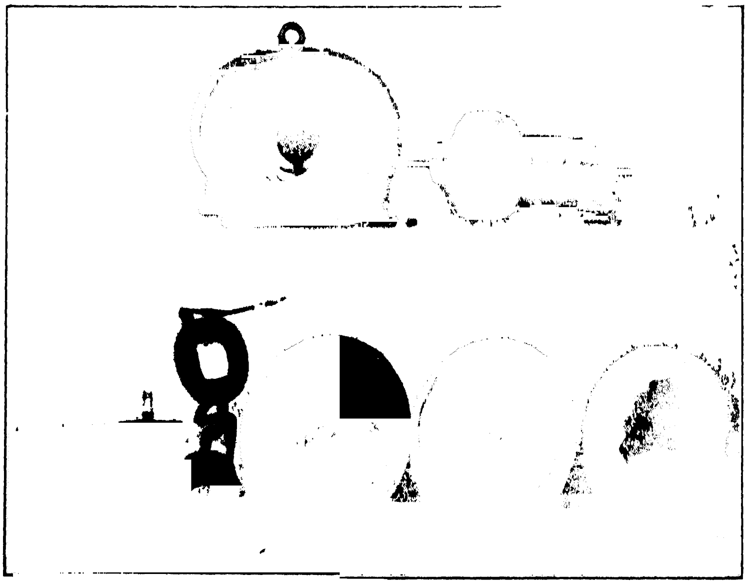


FIG. 2-22. Disassembled view of Crocker-Wheeler 2 kw. motor-generator with alternator of "wound" type.

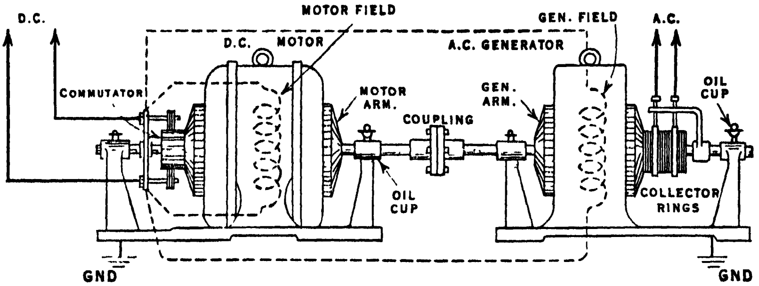


FIG. 2–23. General construction of motor-generator.

2–8. Dynamotors—Dynamotors are employed to change direct current at one voltage to direct current at another voltage. This is very convenient on small yachts and pleasure craft where, from a small battery of low voltage, a high voltage from 300 to 1000 volts can be produced to supply the plates of a vacuum tube transmitter. The dynamotor has two separate armature windings placed on a common rotor. One acts as a motor, the other as a generator. There is but one frame and one set of field magnets. The two windings are connected to commutators at opposite ends of the shaft. The ratio of voltage is fixed when the machine is built; therefore, the output voltage depends on the applied voltage. The field coils receive current from the same source as the motor armature. Figure 2–25 shows the picture of such a machine and Figure 2–26 the fundamental circuit.

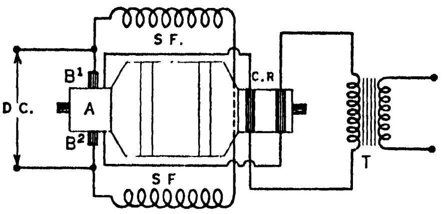


FIG. 2–24. Fundamental circuit of rotary converter.

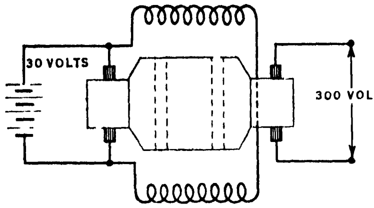


FIG. 2–26. Fundamental circuit of dynamotor.

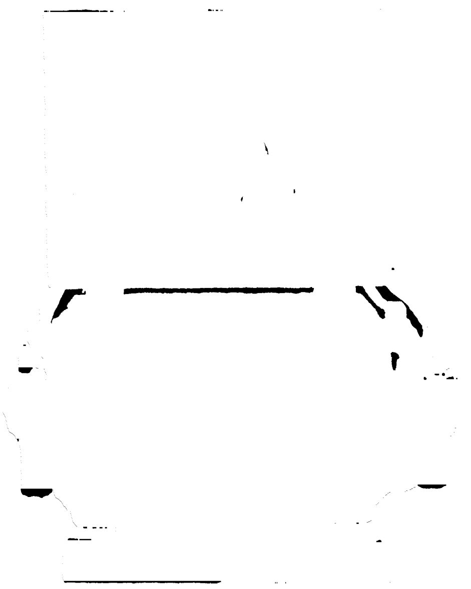


FIG. 2–25. Esco dynamotor and switchboard.

2–9. Care of Motors and Generators—Modern motors and generators are rugged machines but require some care if uninterrupted performance is to be obtained. The following simple rules should be observed:

1. Avoid sparking at the brushes. This may be accomplished by keeping the slip rings, commutator, and brushes clean. The brushes should be replaced when they wear down. Fine sandpaper may be used in cleaning the commutator and slip rings. Emery cloth should never be used because of the metallic particles which may short-circuit segments of the commutator.
2. Bearings should be oiled when necessary.
3. The machine should be cleaned occasionally to prevent the accumulation of dirt and grease.
4. Do not permit the machine to become overloaded or overheated. If a hand starter is employed, the machine should not be started too rapidly nor too slowly.

2–10. Protective Devices—Some means must be provided in a radio transmitter to prevent r-f currents from flowing back into the power leads and thence into the motor and generator windings where they may cause damage.

All power leads are usually run in metal conduit and the conduit grounded. In some installations lead-covered conductors are employed and the lead sheathing grounded. High-frequency currents induced in the conduit or lead covering are effectively grounded, and thus no harm results to the power machinery.

To protect the power machinery, the simple device shown in Figure 2-27 is often employed. The midpoint of the two series-connected condensers is grounded. This offers a path of low impedance to ground for any high-frequency currents in the power leads. Condenser values ranging from 0.1 to 10 μf are commonly employed and are used in the following circuits:

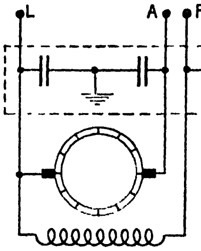


FIG. 2-27 Protective capacitor connected across motor terminals.

1. Across the motor armature.
2. Across the motor field.
3. Across the generator armature.
4. Across the generator field.
5. Across the d-c feeders entering the radio room.

Protective condensers of a motor generator are usually made up as a unit and mounted directly on the frame of the machine. Each terminal of the machine is connected to a condenser and the other terminal of the condenser is connected to the frame of the machine which is grounded.

2-11. Polyphase Systems—A single-phase a-c system is one which is energized by a single source of a-c voltage. Two wires are required to distribute the power in a single-phase system. A two-phase system is energized from two independent, substantially equal voltages that differ in phase by 90°. Three wires are usually employed to distribute the power in a two-phase system, although four wires are sometimes used. A three-phase system is one which is energized by three independent, substantially equal voltages that differ in phase by 120°. Three or four wires are employed to distribute the power of a three-phase system. The expression *polyphase* system refers to any system employing two or more phases; both the two-phase and three-phase systems therefore may be classified as polyphase systems.

2-11a. Two-Phase Systems—Two-phase power can be generated by mounting two single-phase alternator armatures on the same shaft in such a manner that the generated voltages differ by 90 electrical degrees. Two-phase systems were employed mainly to operate induction motors but are no longer in common use, having been superseded to a large extent by the three-phase system.

When the two armature windings of a two-phase generator are connected as shown in Figure 2-28, only three wires are required to transmit the power. This arrangement is known as a two-phase, three-wire system. The center feeder, connected to the point common to both armatures, is called the common wire, while the outside feeders are called the phase wires.

Two different voltages are obtainable from such a system. If a connection is made from either phase wire to the common wire, the armature voltage will be obtained. On the other hand, if the connection is made from phase wire to phase wire, the voltage obtained will be the armature voltage times $\sqrt{2}$.

As an example, let us assume that the voltage from each of the two armatures of Figure 2-28 is 120 volts. A connection across wires *A* and *B*, or *B* and *C* will give 120 volts; however, a connection across wires *A* and *C* will give 169 volts.

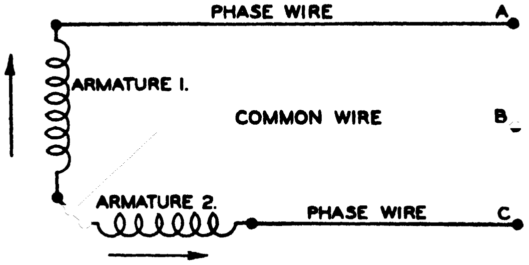


FIG. 2-28. Two-phase three-wire system.

A four-wire, two-phase system, Figure 2-29, simply employs separate feeders for each phase in the same manner that would be employed for two single-phase supplies. However, the two voltages of a four-wire, two-phase system are displaced by 90°. Only a single voltage—the armature voltage—can be obtained from such a system as there is no connection between the two armatures.

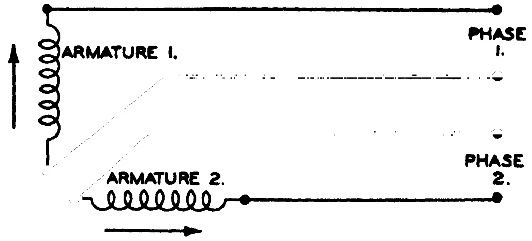


FIG. 2-29. Two-phase four-wire system.

2-11b. Three-phase Systems—A three-phase alternator has three separate windings so arranged that three equal voltages, each separated by 120°, are generated. Three-phase systems are in wide use in the distribution of electrical power in this country, having replaced two-phase systems almost completely.

If the three armature windings of a three-phase alternator are connected as in Figure 2–30, they are said to be star- or Y-connected. If connected in the manner shown in Figure 2–31, they are said to be delta (Δ)-connected.

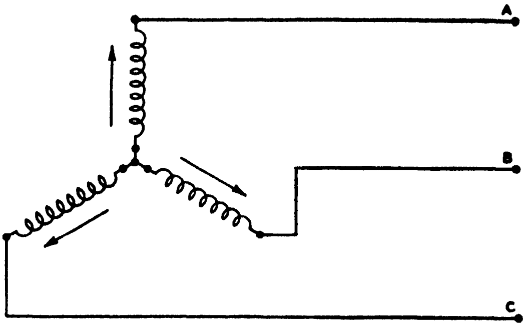


Fig. 2–30. Y- or star-connected armature.

A three-phase, three-wire system may be supplied by either a Y-connected or a delta-connected generator. When a delta-connected generator is employed, the voltage across any two line wires is the same as the voltage across any of the armature windings. For example, if a voltage of 120 is maintained across each of the three armature windings, Figure 2–31, a voltage of 120 will be obtained across wires *A* and *B*, *A* and *C*, or *B* and *C*.

In the case of a three-wire, star-connected system, the armature and line voltages are not the same, the line voltage being $\sqrt{3}$ (1.73) times greater than the armature voltage. For example, if the three armature voltages of Figure 2–30 were 120, the voltages across line wires *A* and *B*, *A* and *C*, or *B* and C would be 120 × $\sqrt{3}$ or 208 volts.

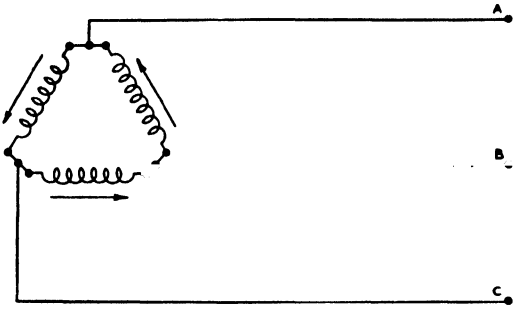


Fig. 2–31. Delta-connected armature.

A three-phase, four-wire arrangement is shown in Figure 2–32. A Y-connected generator must be used in such a system as the fourth, or neutral wire, connects to the point common to all three armature windings. With this system, a connection to any line wire and neutral wire will give a voltage equal to the armature voltages, whereas a connection between any two line wires will, as in the case of the three-wire system, give a voltage $\sqrt{3}$ times greater than the armature voltage. As an example, assuming again that each of the armature windings are delivering 120 volts, the voltage between any two line wires will be 208 volts, whereas the voltage between any line wire and the neutral wire will be

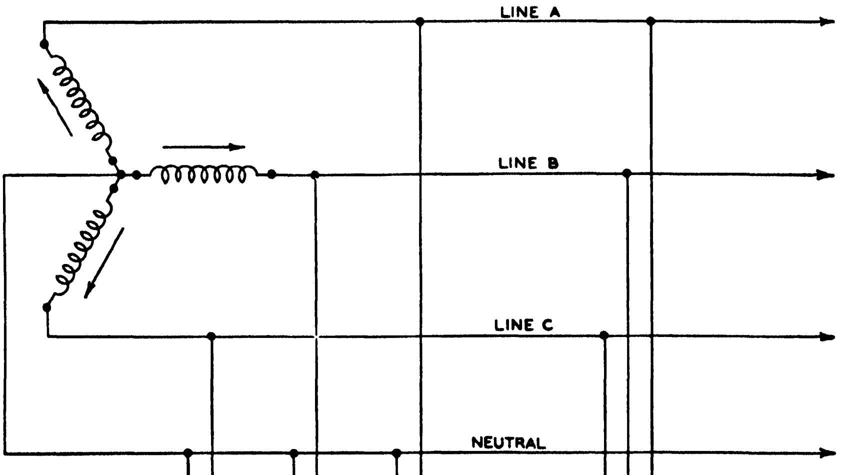


Fig. 2–32. Three-phase four-wire system supplying power to lighting circuits and three-phase motors.

120 volts. This arrangement is quite useful in the arrangement shown in Figure 2–32, where the three phases combined are employed to operate a three-phase motor or other equipment requiring the simultaneous use of all three phases, and the individual line wires operating against the neutral wire are employed to supply lighting circuits.

From the above discussion, it must not be assumed that polyphase alternators are always wound to produce a voltage of 120 from each armature winding. As a matter of fact, the generated voltages are usually much higher, being stepped-down by means of suitable polyphase transformers (which also may be either Y- or delta-connected) at the point of use.

CHAPTER 3

BATTERIES

In general, there are two basic types of cells—the primary cell and the secondary, or storage, cell. A primary cell is a device for producing electrical energy by electrochemical action. Some elements of the cell are consumed during the process and, when all useful energy has been utilized, the cell must be discarded or certain parts renewed.

The secondary, or storage, cell differs from the primary cell in that when it has given out all the energy the chemical action enables it to supply, instead of requiring new elements, the cell can be completely regenerated or brought back to the original condition by passing a current through it in a direction opposite to that in which the flow took place during the discharge. The charging current simply reverses the chemical action and restores the plates and electrolyte to the composition they had before the discharge.

A storage cell does not act as a storage place for electricity as its name may imply. The charging current merely restores the active material of the plates and electrolyte to their original condition. The storage cell is completely reversible and can be repeatedly charged and discharged until the plates are worn out by the dislodging of the active material.

A battery is an assembly of two or more cells connected in a manner to provide greater voltage or capacity than obtainable from a single cell. From this it can be seen that the word "battery" should only be used when speaking of a bank of cells and the word "cell" when speaking of a single cell. In common practice, however, the two words are often erroneously used interchangeably.

3–1. Primary Cells—One of the most elementary primary cells is the zinc-copper-acid type illustrated in Figure 3-1. It consists of two metal plates, one copper the other zinc, suspended in a glass containing a dilute solution of sulphuric acid. When the switch is closed, the voltmeter will indicate a voltage of about one volt and the ammeter will indicate a small current flow dependent on the value of the resistor *R*. It will be found that the zinc electrode is negative in polarity whereas the copper electrode is positive. The direction of electron flow in the external circuit is from zinc anode to copper cathode.

The zinc anode assumes a negative polarity as a result of the zinc ions leaving its surface while the zinc is attacked by the electrolyte. At the same time positively charged hydrogen ions are liberated. The hydrogen ions tend to be repelled from the zinc because of the positive charge in the solution surrounding the zinc caused by other hydrogen ions. Upon reaching the copper plate, they give up their positive charge and then collect around the copper plate as hydrogen bubbles.

After operation of the cell for a short time, the hydrogen, a nonconductor, accumulates sufficiently to reduce the voltage of the cell until its output is negligible. This reduction of output due to the hydrogen formation around the cathode is known as "polarization." Polarization is a temporary suspension of the functioning of the cell. The cell's usefulness will be restored if the load is removed and the cell given time to recover. Polarization has been overcome in practical primary cells by the introduction into the cell of a substance rich in oxygen which combines with the hydrogen to form water. Manganese dioxide containing one atom of manganese and two of oxygen is commonly used for this purpose.

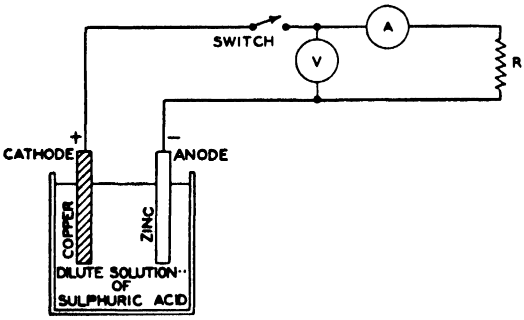


FIG. 3–1. Elementary primary cell.

Another difficulty sometimes encountered in primary cells is known as "local action." Local action occurs when the zinc of the negative electrode is not pure. When impure zinc is used, a multitude of miniature cells are formed at the surface of the zinc with the result that the zinc will be consumed even if the cell is not in use. Commercial zinc, containing some impurities, may be used provided it is amalgamated, that is, coated with mercury. This treatment is effective in preventing local action. Another method of amalgamating the zinc which is sometimes used consists of adding a small amount of mercuric salts to the electrolyte. This will be deposited on the zinc and protect it against local action.

3–1a. The Dry Cell—Of all the types of primary cells the dry cell is by far the most commonly used. The dry cell is frequently employed to operate portable radio receivers, amplifiers, and other electronic devices. A cut-away view illustrating the internal construction of a dry cell is shown in Figure 3–2. The anode is zinc, which serves the double purpose of negative electrode and container for the cell. The positive electrode consists of a carbon rod surrounded by a mixture of granulated carbon and the depolarizer manganese dioxide. The carbon and the manganese dioxide are saturated with the electrolyte which is usually a mixture of salammoniac and zinc chloride. This mixture of carbon, manganese dioxide, and electrolyte is separated from the zinc by means of porous paper, cloth, or a thin layer of organic compound such as starch. Terminals are fastened to the zinc container and carbon rod. A layer of sealing wax at the top seals the cell which is then placed in a cardboard container for protection and insulation.

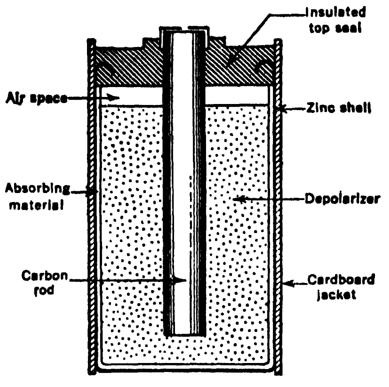


FIG. 3–2. Cut-away view of dry cell.

A single dry cell provides a voltage of approximately 1.5 volts when new. This voltage will decrease as power is taken from the cell and the end of its useful life is reached when the voltage drops to approximately 0.9 volts. The cell must then be discarded and replaced. The length of service is dependent upon the size of the cell.

Dry cell batteries (Figure 3–3), containing a large number of small cells connected in series, are often used when high voltage is required for the operation of portable radio equipment. Such units, which are manufactured in small compact units, are known as "B" batteries. A common size of this type of battery contains 30 cells and supplies a voltage of 45 volts.

3–2. Storage Batteries—Storage batteries will be found in virtually every ship and aircraft radio installation. On shipboard, they are used to operate receivers and as an emergency source of power to operate the radio transmitter, to start gasoline-driven emergency generators, and for routine operation of direction finders, auto-alarm devices, and lifeboat radios. On aircraft installations they are employed to operate dynamotors and to supply power to the filaments of the receiving and transmitting tubes. There are two types of storage batteries in general use, the lead-acid type and the nickel-alkaline or Edison type. Both types, as well as charging circuits, are described in the following paragraphs.

3–3. Lead-Acid Battery—In general, the lead-plate, sulphuric-acid cell consists of lead plates immersed in a dilute sulphuric acid solution. If two lead plates are immersed in a dilute solution of sulphuric acid and then connected to a charging current, it will soon be noted that the character of the plates has changed. One of the plates will have become brown in color because of the formation of peroxide of lead; the other plate will be light gray in color as a result of the formation of pure lead on its surface. Now if the charging current is dis-

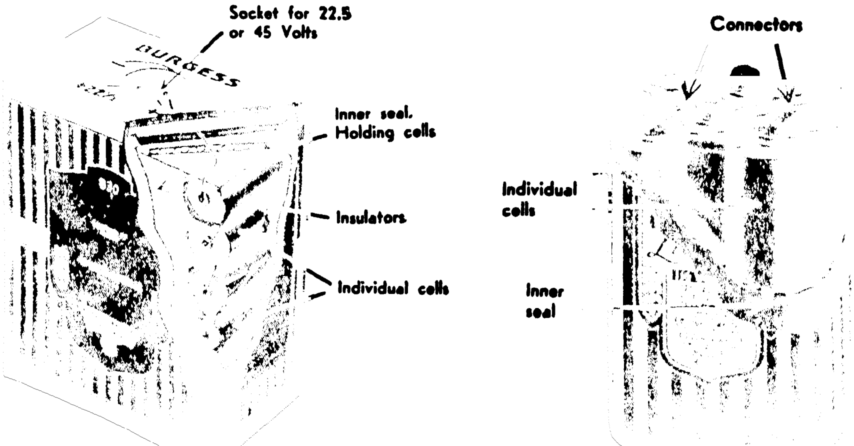


FIG. 3–3. Dry batteries opened to show assembly of cells.
At left: 45-volt radio B battery with 30 cells in series. At right: 1½-volt general utility battery of 4 cells in parallel.

connected and a voltmeter connected across the cell terminals, it will be found that the cell has become a source of electrical energy, the brown plate being positive in polarity and the gray plate negative. Current will flow from this cell in a reverse direction from the charging current.

3–3a. Plate Construction—The average commercial cell plates are made by pasting the active elements into lead grids. After the grids are cast, they are pasted with oxides of lead made into a paste of special composition which sets, in drying, like cement. The plates then go through an electrochemical process which converts the material of the positive plate into brown peroxide of lead and that of the negative plate into gray, spongy lead. Plates of this type of construction are illustrated in Figures 3–4 and 3–5.

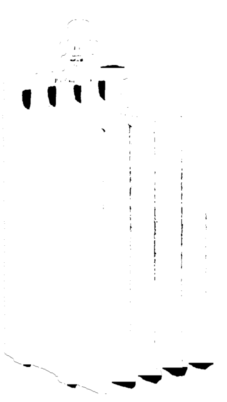


Fig. 3–4. Negative plates of lead battery.

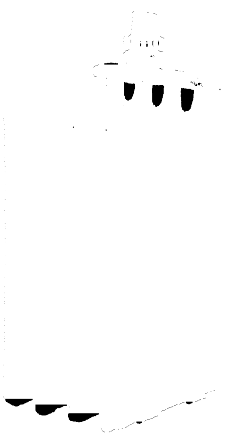


Fig. 3–5. Positive plates of lead battery.

Both the positive and negative plates are provided with an extension or lug, and they are so assembled that all the positive lugs come at one side of the container and all the negative lugs at the other, enabling all the lugs of each set to be burned together with a connecting strap and thus giving one positive and one negative pole. The burning is done by a hydrogen flame, which melts the metal of both lugs and strap into an integral union. There is usually one more negative plate than positive, both outside plates of the grid being negative. The straps are made of hard lead alloy and are provided with posts to which the cell connections are made.

3–3b. Separators—To prevent contact between adjacent plates, separators made of light pieces of wood veneer, hard rubber, glass mat, porous rubber, or other material are placed between them. The spacers are usually grooved or perforated to allow free circulation of electrolyte and permit the release of bubbles of gas.

3–3c. Electrolyte—The electrolyte for the lead-acid cell is a dilute solution of pure sulphuric acid. The strength of the solution varies slightly in cells of different types.

3–3d. Containers—The container for portable batteries is usually made of a hard-rubber compound; but larger batteries, which are used in a stationary position, are generally contained in glass or lead-lined tanks. The plates rest on stiff ribs or ridges in the bottom of the container allowing space for the accumulation of sediment.

3–3e. Voltage Characteristics—The terminal voltage of a fully charged lead-acid cell is approximately 2 volts. This voltage is gradually reduced as the cell is discharged until it reaches a value of 1.7 volts at which time practically the complete capacity of the cell has been delivered. It is not desirable to continue the discharge beyond this point, except when the cell is delivering current at much more than normal rate; for example, at 10 times the normal rate of discharge it is permissible to continue the discharge until the voltage of the cell has fallen to about 1.4 volts.

3–3f. Unit of Capacity—The capacity of the storage battery is expressed in ampere-hours. The ampere-hour is a unit of measurement indicating a current flow of one ampere for one hour. The capacity of a storage battery capable of delivering 10 amp for 12 hours could therefore be expressed as 120 ampere-hours. The ampere-hour capacity of a cell depends for the most part upon the number, size, and thickness of the plates, the concentration of the electrolyte, the temperature, and the discharge rate.

3–3g. Discharge Rate—In rating the capacity of the storage battery it is necessary for the manufacturer to state the normal discharge rate. This is sometimes given in amperes and at other times in hours. If either is known, the other can easily be calculated. The capacity of the battery, in ampere-hours, is based on the battery being discharged at the normal discharge rate. If current is taken from the battery at lower than the normal discharge rate, the battery will give a greater ampere-hour capacity. If current is removed at a greater than normal rate, the capacity will be lower. The capacity rating of portable and vehicle batteries is usually based on a 20-hour discharge rate, that is, a battery rated at 120 ampere-hours will deliver 6 amp for 20 hours.

3–3h. Discharge Voltage Limit—The discharge of a battery must be stopped when it has reached the discharge voltage limit, which depends upon the type of cell, the concentration of the electrolyte, and the rate of discharge. The discharge voltage limit, when given on the battery name plate, is for the normal discharge rate.

As stated earlier, a battery discharged at a high rate can be carried to a lower voltage limit than a battery discharged at a long, low rate. During high rates of discharge the chemical reactions in the cell are very rapid, forming sulphate in the outer layers of the active material of the plates, making it difficult for the acid to reach the interior portions of the plates and increasing the internal resistance of the cell, causing the voltage to drop quickly. It may, therefore, be allowed to drop lower than during either a long, low-rate discharge or an intermittent-rate discharge, since only a fraction of the capacity of the cell is withdrawn even though the voltage is carried lower.

3–3i. Chemical Action During Charge and Discharge—When a cell is fully charged, the negative plate is lead sponge, Pb, and the positive plate is lead peroxide, PbO_2, the specific gravity of the electrolyte (sulphuric acid, H_2SO_4 and water, H_2O) is at its maximum between 1.210 and 1.220 for large stationary batteries and 1.250 to 1.280 for portable and vehicle batteries at temperatures of 70 to 80° F. Chemical energy is stored in the cell in this condition.

When a battery is supplying energy (discharging), the H_2SO_4 of the electrolyte is divided into H_2 and SO_4. The H_2 combines with some of the oxygen of the lead peroxide and forms water, the SO_4 combining with the liberated Pb of the positive plate to form lead sulphate. The SO_4 also forms lead sulphate at the negative, Pb, plate. As the discharge progresses, both plates are finally reduced so that they contain considerable lead sulphate, $PbSO_4$. The water formed has diluted the acid, lowering the specific gravity of the electrolyte. When the plates are entirely sulphated, current will cease, since the plates are identical, and any cell requires two dissimilar plates in the electrolyte. In practice, however, the discharge is always stopped before the plates have become entirely reduced to lead sulphate. The lead sulphate that has formed by the acid in contact with the plates is more bulky than the lead sponge or lead peroxide, just as copper sulphate on copper, or iron rust on iron, is more bulky than the amount of copper or iron eaten away. The lead sulphate, because of its increased volume, fills the pores of the active material, until finally, near the end of the discharge, the circulation of acid in the pores of the plates is retarded because of the increased bulk of the lead sulphate. Since the acid cannot get into the plates to maintain the normal action, the cell becomes less active, as indicated by the drop in voltage.

During charge, when a current from an external source is passed through the battery in a reverse direction, the chemical action is reversed. It will be remembered that during the discharge the acid of the electrolyte went into and combined with the active material, filling its pores with sulphate and causing the electrolyte to become weaker. Reversing the current through this sulphate in the plates restores the active material to its original condition and returns the acid to the electrolyte. Thus, during charge, the lead sulphate, $PbSO_4$, on the positive plate is converted into lead peroxide, PbO_2. The lead sulphate on the negative plate is converted into sponge lead, Pb. The electrolyte gradually becomes stronger as the SO_4 from the plates combines with the hydrogen to form acid, H_2SO_4, until no more sulphate remains and all the acid has been returned to the electrolyte. It will then be of the same strength as before the discharge and the same acid will be ready to be used over again during the next discharge.

Since there is no loss of acid, none should be added to the electrolyte. The acid absorbed by the plates during discharge is, during charge, driven from the plates by the charging current and restored to the electrolyte, thereby making the battery available for another discharge cycle.

3–3j. Charging Rate—A battery can be charged at as high a rate as desired, provided that the charging current does not cause excessive gassing or produce a cell temperature in excess of 110° F. When fully discharged, the battery can absorb current at the highest rate. As the charge progresses, the plates can no longer absorb current at the same rate and the excess current goes to form gas and heat. In a battery which is charged or nearly charged, the plates can absorb current without excessive gassing only at a low rate; a high charge rate will be almost entirely used in forming gas, resulting in high temperature and dislodgement of the active material from the plates and consequent shortening of the battery life.

Thick-plate lead-acid batteries are not ordinarily to be given a full charge (from a completely discharged condition) in less than 8 to 12 hours. Thin-plate batteries may be charged more rapidly but careful supervision is required if the time for a complete charge is less than 5 hours. It is quite possible to damage a storage battery during a single fast charge.

3–3k. Determining State of Charge—One method of determining the state of charge of a storage battery is a reading of the cell voltages. Voltage readings must be taken with the battery delivering current, since the open-circuit voltage gives no reliable indication of the battery condition. The voltage at the beginning of the discharge is approximately 2.06 volts per cell and at the end of discharge has fallen to 1.7 to 1.75 volts per cell. It will be recalled that the voltage may fall far below this during a fast discharge; therefore, a voltage reading is only a rough indication of the state of charge.

A far better indication of the state of charge is given by reading the specific gravity of the electrolyte. The normal specific gravity of the electrolyte should be, with the cells fully charged, between 1.270 to 1.280 for portable and vehicle batteries and 1.210 to 1.240 for large stationary batteries. During discharge, the specific gravity of the electrolyte of portable and vehicle batteries falls 100 to 150 points; therefore, this type of cell should be charged when the specific gravity reaches 1.180 to 1.130.

The reduction in specific gravity of stationary batteries during discharge is usually not as great. The manufacturer's instructions should be consulted to find the recommended minimum specific gravity value.

3-3l. The Hydrometer—The specific gravity of the electrolyte of the lead-acid cell is read by means of a hydrometer (Figure 3-6). The hydrometer is a small glass tube, closed at both ends, and weighted with lead shot at one of them. Inside the upper part of the tube is a graduated scale marked from 1.100 to 1.300. The hydrometer floats when placed in a fluid, displacing the fluid in accordance with the fluid's specific gravity. The density of the fluid is read at the point where the water line of the fluid meets the graduated scale of the hydrometer.

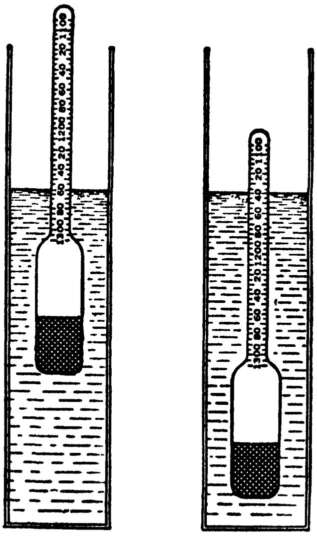


FIG. 3-6. Acid hydrometer showing difference in specific gravity of two electrolytes.

Hydrometers for use with portable and vehicle batteries are usually of the syringe type. The syringe permits the removal of a small portion of the cell electrolyte into a glass tube containing the hydrometer. After the specific gravity has been read, the solution is returned to the cell. In large stationary batteries the hydrometer is usually immersed directly into the electrolyte of the cell.

Although rarely employed in this country, hydrometers graduated in the Baumé scale may sometimes be encountered in foreign countries. The Baumé hydrometer operates in the same manner as the specific gravity hydrometer except that it is calibrated in Baumé degrees. Should a hydrometer of this type be used, the reading may be converted to specific gravity by means of the following equation:

$$\text{Specific Gravity} = \frac{145}{145 - \text{Hydrometer reading in Baumé degrees}}$$

For example, a reading on a Baumé hydrometer of 29° would be converted to specific gravity in the following manner.

$$\text{Specific Gravity} = \frac{145}{145 - 29} = 1.250$$

3-3m. Height of Electrolyte—The electrolyte should be kept at the correct height above the tops of the plates at all times. This height varies with different makes and types of batteries, but in general it should be kept at as high a level as will allow the battery to be charged without overflowing, that is, without causing the electrolyte to run out at the filling tubes while charging.

3-3n. Use of Pure Water—Only approved water should be used to replace that lost by evaporation. Distilled (but not merely boiled) water is approved. Water taken from wells, springs or rivers is often satisfactory, but should not be used unless approved. Never transport or store water in any metallic vessel except lead. Keep the receptacle clean and covered to keep out impurities. Glass, earthenware, rubber, or wooden receptacles that have not been used for any other purpose are satisfactory. If water is drawn from a tap, it should be allowed to run a few minutes before using it.

3-3o. Specific Gravity Adjustment—It should never be necessary to add acid to the electrolyte except to replace actual loss of acid due to electrolyte spillage or a leaky container.

If the specific gravity of a cell is too low and adjustment is necessary, first, be sure that charging will not raise the specific gravity. To check this, charge the cell until the specific gravity shows no rise and then charge at a low rate for five additional hours. A specific gravity adjustment should never be made on a cell which does not gas during charge. To adjust low gravity, new electrolyte of 1.300 specific gravity should be added to the cell instead of water when replacing evaporation loss until the specific gravity at the end of a complete charge is up to normal. No further adjustment of electrolyte should be made.

Sulphuric acid is usually sold and shipped in concentrated form. It is an oily, syrupy liquid, and much heavier than water, having a specific gravity of 1.835. In purchasing the acid, care must be taken to specify that it be chemically pure. To prepare the acid for use in storage cells, one part of acid is added to about four parts of water. *Never add water to the acid*, since the chemical action of this combination is quite violent and there is danger of the steam from the water throwing acid on the clothes or hands. The *acid* must be slowly added *to the water* while constantly stirring the mixture. This process must be carried on in a clean glass, earthenware, or lead container. If placed in an ordinary metal container, chemical action will start at once between the acid and the metal and the electrolyte will become contaminated.

3–3p. Impurities—Impurities in the elctrolyte will cause a cell to work irregularly. Should it be known that any impurity has entered the cell, it should be removed at once. If removal has been delayed and any considerable amount of foreign matter becomes dissolved in the electrolyte, this solution should be replaced with new solution immediately, thoroughly flushing the cell with water before putting in the new electrolyte.

3–3q. Buckled Plates—Buckled plates are plates which have been bent and warped out of shape Lead, like most material, will expand under the action of heat. but it has a very low elastic limit and, once expanded, it will remain in that condition. If the temperature is kept below 110° F, plates will not buckle. *Most buckled plates are caused by continued overdischarge or lack of charge.*

3–3r. Broken Container—If a container should be broken, do not allow the plates to dry. If there is no extra container on hand, remove the cell (either with or without its container) from the circuit, immerse it in a wooden bucket filled with water and keep it covered with water until ready to reinstall it.

3–3s. Sulphation—A lead-acid storage battery should be charged as soon as possible after discharge. If it is allowed to stand for a considerable length of time in a discharged condition, the lead sulphate which is formed in the active material of the plate during normal discharge will change in form and become hard and insoluble in sulphuric acid. This sulphate has a high resistance and is very difficult to remove. Because of the hard, insoluble nature of this material it will cause, if allowed to accumulate on the active material to any appreciable extent, an increase in the internal resistance of the battery and a reduction in its capacity. When this occurs, the battery is said to be ***sulphated.*** If allowed to go unchecked, this sulphate continues to increase in volume and may bend or buckle the plates. If recognized in its early stages, sulphation may be remedied by giving the battery a long, continued charge at a low charging rate. If this is not effective, the battery should be given a series of low-rate charges and discharges until it is restored to normal condition.

3–3t. Freezing Point of Electrolyte—The freezing temperature of the electrolyte of the lead acid cell varies with the concentration of the solution and, therefore, depends upon the state of charge of the cell. As the concentration of the solution is much lower when the battery is discharged, danger of freezing is greatest at that time. The electrolyte of a discharged cell may freeze at temperatures of − 10° C (+ 14° F) or even higher. When the cell is fully charged, danger of freezing is much less, being about − 40° C (− 40° F) for portable and vehicle batteries.

3–4. The Edison Battery—The nickel-alkaline type of storage battery is commonly known as the Edison battery. It differs in construction, chemical action, and electrical characteristics from the lead-acid battery. It is in common use, although infrequently found in marine or aircraft installations.

3–4a. Electrolyte—The electrolyte used in Edison cells is composed of pure distilled water combined with a 21 percent solution of potassium hydrate mixed with a small portion of lithium hydrate. It has a specific gravity of approximately 1.200 at 60° F. and a freezing point of − 28° C (− 18.4° F) regardless of the state of charge.

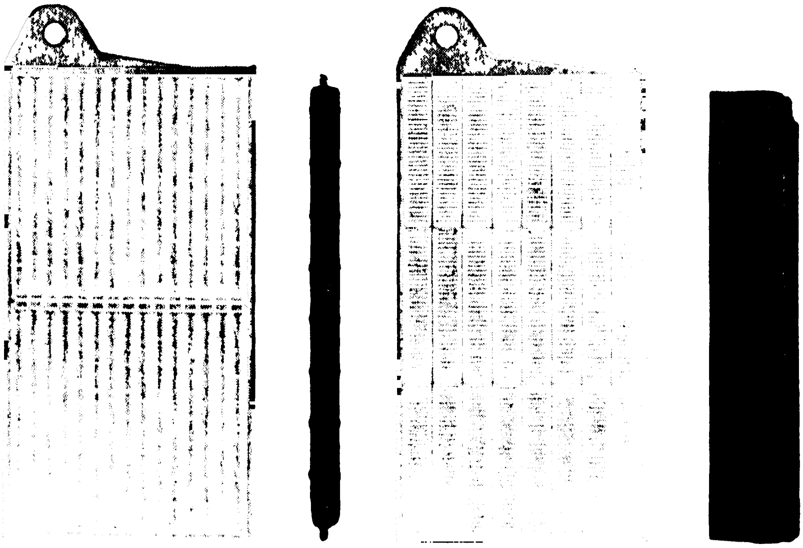


FIG. 3–7. Plates of the nickel-alkaline cell with enlarged views of positive tube and negative pocket.

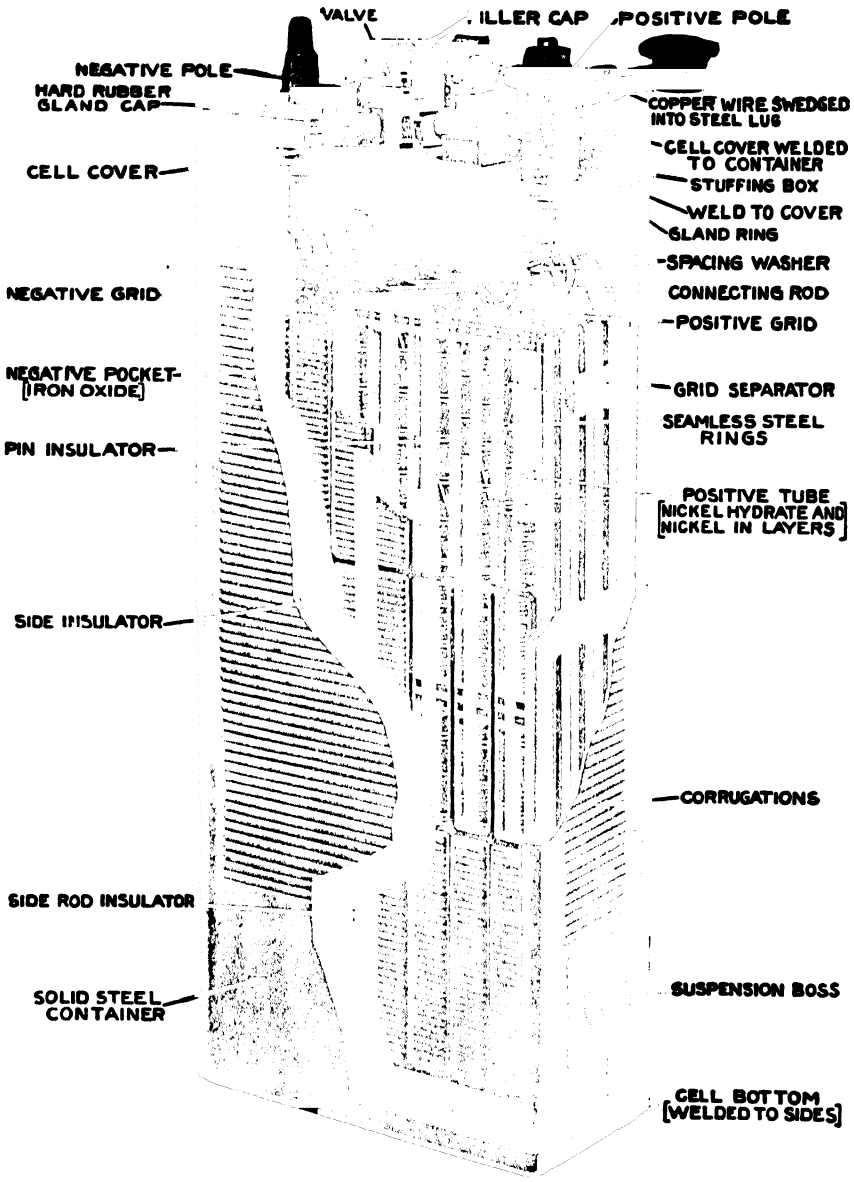


FIG. 3–8. Sectional view of Edison storage battery.

The specific gravity of the cells changes little with charge and discharge and, therefore, is of no value in determining the condition of the cell. However, throughout the useful life of the cell the electrolyte gradually weakens, and for this reason specific gravity readings are of value in determining when a renewal of solution is necessary. The low limit of specific gravity is 1.160 and is usually accompanied by sluggishness and a temporary loss of capacity.

3–4b. Plate Construction—The positive plate is made up of many perforated, nickel-plated steel tubes into which have been packed, under heavy pressure, alternate layers of nickel hydrate, the positive active material, and pure flake nickel. Each tube is reinforced by eight seamless steel rings. The negative plate is composed of a steel grid supporting many perforated nickel-plated steel pockets. Iron oxide, the negative active material, is loaded into these pockets, which are then secured to the grids by means of hydraulic pressure.

3–4c. Chemical Action—The fundamental principle of the Edison storage battery is the oxidation and reduction of metals in an electrolyte which neither combines with nor dissolves either the metals or their oxides. Although the electrolyte is decomposed by charge and discharge, it is reformed again in equal quantities and, therefore, its density and conductivity remains the same over a long period of time. Because the active materials of the plates are insoluble in the electrolyte, no chemical decomposition takes place therein.

The chemical reactions in charging are (1) the oxidation from a lower to a higher oxide of nickel in the positive plate, and (2) the reduction from iron oxide to metallic iron in the negative plate. The oxidation and reduction are performed by the oxygen and hydrogen set free at the respective poles by the electrolytic decomposition of water during the charge.

The discharge of the cell is simply the reverse of the above reactions, the hydrogen reducing the higher oxide of nickel to a lower oxide, and the oxygen oxidizing the iron to iron oxide.

3–4d. Container—The container of the Edison cell is made of nickel-plated sheet steel with the sides corrugated to provide additional strength. The sides, top, and bottom are welded. The terminal posts pass through openings in the top of the cell and are sealed by means of rubber gaskets and bushings. To indicate polarity, the bushing at the positive pole is red, whereas that at the negative pole is black. A filler cap is provided to add water and also to allow for the escape of gas. The cap is of such construction that the cell can be tipped to an angle of 45° without spilling the electrolyte.

3–4e. Voltage—The average voltage from an Edison cell during discharge is 1.2 volts. The fully charged voltage is slightly higher, being about 1.4 volts, dropping to about 1.0 volts when discharged.

3–4f. Height of Electrolyte—The height of the electrolyte should always be kept at least one-half inch above the tops of the plates. The exact height varies with different types of cells and the manufacturer's instructions should be consulted for the maximum height permissible. Distilled or approved water should be used.

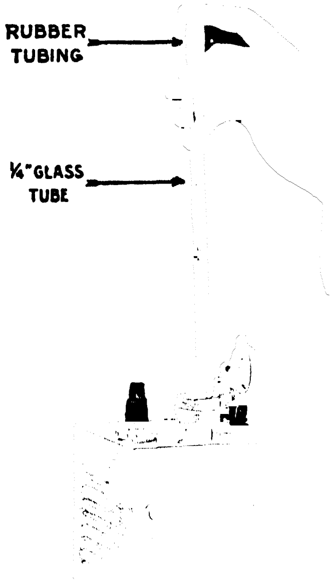


Fig. 3–9. Testing height of solution.

A convenient method of checking the height of the electrolyte is shown in Figure 3–9. A glass tube about 8 inches in length and not less than ³⁄₁₆ inch inside diameter, provided with a short length of rubber tubing forced over one end, is inserted in the cell until it touches the top of the plates. The upper end of the rubber tubing is then closed with the finger and withdrawn from the cell. The height of the liquid in the tube indicates the height of the electrolyte above the top of the plates.

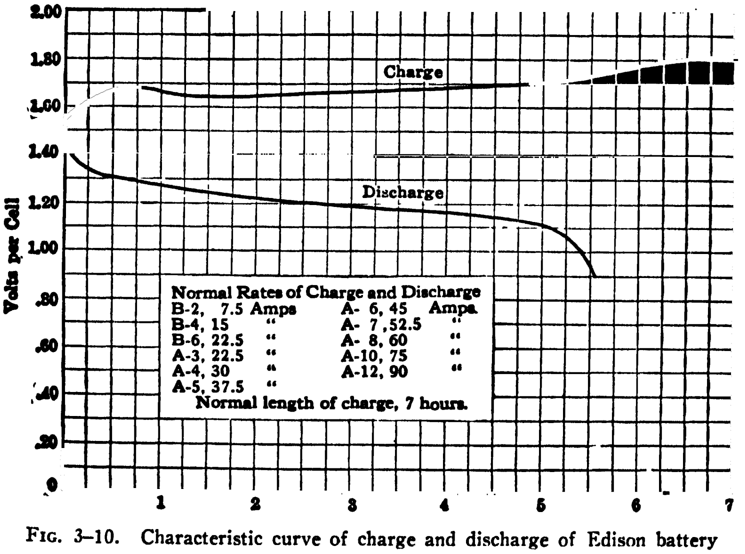


Fig. 3–10. Characteristic curve of charge and discharge of Edison battery

3–4g. Characteristics and Care of Edison Cell— Edison cells will not be injured by abuse that would almost certainly destroy a lead-acid cell. They can be left idle for long periods of time partly or completely discharged without damage. They can be completely discharged until the voltage is zero and, even if accidentally charged in the wrong direction, will not be injured.

The Edison cell is lighter in weight than a lead-acid cell of equivalent capacity. The voltage per cell is lower and the initial cost of an Edison battery is higher than a lead-acid battery, although this may be offset over a period of time because of its longer life. The Edison battery has a higher internal resistance than the lead-acid battery, making it unsuitable for some applications requiring very high discharge rates, such as turning the starting motor in automobiles.

The following suggestions and precautions should be observed to keep a battery of Edison cells in good condition:

1. Never use a hydrometer syringe or any other utensil that has been used with lead-acid cells to check or add water to an Edison cell.
2. Never add anything to the electrolyte to prevent freezing. The freezing point of the electrolyte is − 28° C (− 18° F), which is a temperature not often encountered. No permanent injury is caused by the severest cold.
3. During charge and immediately following charge, batteries give off hydrogen gas. Inasmuch as this gas is explosive in the presence of a spark or open flame, extreme care should be taken to see that no spark or open flame is permitted near the battery or its compartment. All connections should be kept tight to eliminate the possibility of sparking due to loose connections.
4. Keep the cells clean and the vent caps free from crystals of potash salts which may accumulate on the cells. Cell tops of marine batteries are coated with rosin vaseline compound. If this is removed, it should be replaced with rosin vaseline or, if none is available, with regular vaseline.

3–5. Charging Storage Batteries— Storage batteries are usually charged by connecting them to a suitable constant-potential source of direct current. The positive terminal of the battery must be connected to the positive terminal of the charging source, and the negative terminal of the battery to the negative terminal of the charging source. Alternating current cannot be used to charge a battery, but it is often rectified and the resulting pulsating d.c. employed for charging. The voltage of the charging source must always exceed the maximum voltage of the storage battery because the voltage of the battery exerts a back e.m.f. on the charging voltage. If the back e.m.f. of the battery is greater than the charging voltage, no charging current will flow through the battery.

A variable resistance is usually connected in series with the charging circuit to regulate the amount of current flowing through the battery. It has already been shown that the charging rate can be considerably higher at the start of the charge but must be decreased when excessive gassing occurs or when the temperature of the cell becomes too high. The variable resistor provides the means of controlling the charging current.

A lamp bank provides a convenient method of adjusting the correct charging rate to a battery. An arrangement of this type is shown in Figure 3–11. In order to increase the charging rate, the number of lamps connected in parallel are increased. To decrease the charging rate, the number of lamps in parallel should be decreased. Lamps with a high wattage rating will increase the charging rate, whereas small lamps decrease the charging rate. There are also resistance coils which can be conveniently screwed into a lamp socket. This type of resistance unit has sufficient current-carrying capacity to replace several lamps which would otherwise be necessary in order to secure the same charging rate. A protective device in the form of an underload circuit breaker is usually employed in charging circuits. In the event the charging voltage is cut off or drops below that of the battery, the circuit is interrupted, preventing the battery from dis-

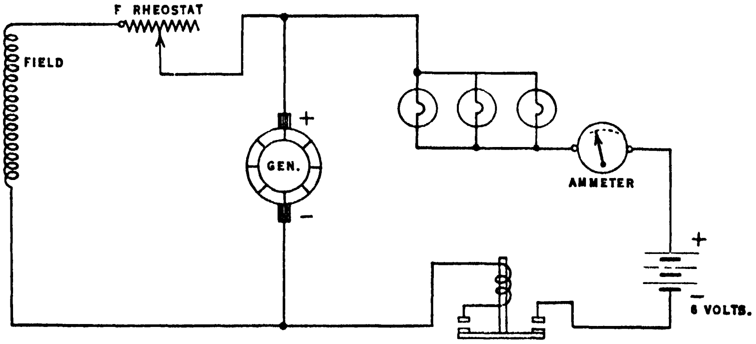


Fig. 3–11. Charging circuit wth lamp bank resistance and underload circuit breaker.

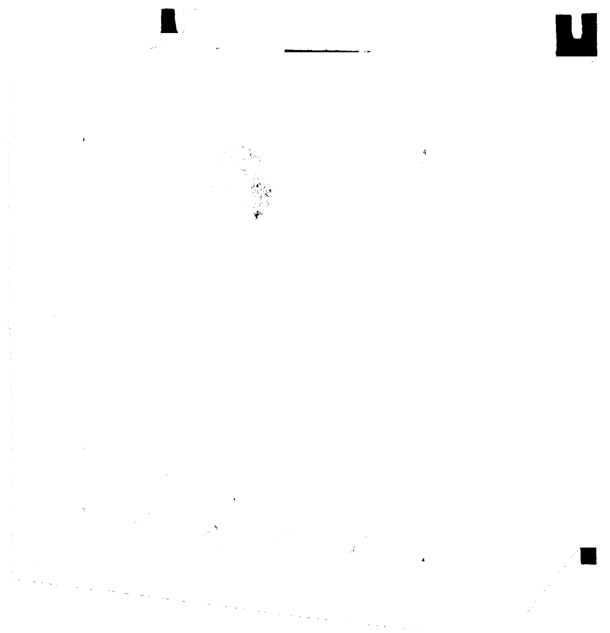


FIG. 3–12. Battery charge-discharge control panel.

charging through the generator. Should the battery discharge through the generator, it may result in a reversal of the residual magnetism of the field poles and, consequently, the output of the generator.

3–5a. Determination of Polarity—The polarity of the charging voltage may be determined in the following ways:

1. By a d-c voltmeter of the movable coil type.
2. By use of a raw potato.
3. By dipping the terminals in a glass of plain or salt water.

Direct-current voltmeters of the movable coil type have the correct polarity marked on the binding posts. If connected properly to a source of direct current, the needle will move in the correct direction on the scale, but, if connected improperly, the needle will move off the scale in a direction to the left of the zero position. The wire connected to the positive terminal of the voltmeter is the positive terminal of the mains and the other, of course, the negative terminal.

Inserting the wires about an inch or two apart momentarily into a raw potato provides a path for a small current to flow. The starch of the potato is decomposed, causing that portion of it surrounding the positive terminal to turn blue.

When the terminals are dipped in a glass of plain or salt water, bubbles will appear at the negative terminal.

3–5b. Charging When Battery Voltage Exceeds That of Generator—It has already been stated that in order to charge a battery the charging voltage must exceed that of the battery. Occasionally batteries employed aboard ships supply a total voltage of 120 or more. Usually, Edison batteries in such installations have 90 or more cells, and the lead-plate batteries have 60 cells. In order to charge such batteries from the ship's generator, which normally supplies 110 volts, the battery is split into two equal banks and the two banks are charged in parallel. When placed on discharge, they are connected in series. This is accomplished by either a three- or four-pole double-throw switch.

3–5c. Trickle Charge—A method of charging a battery held ready for emergency work or a battery not in service is known as a "trickle charge." A trickle charge is a continuous charge at a low rate, approximately equal to the internal losses of the battery and suitable to maintain the battery in a fully charged condition. With this method a small charging current is passed continually through the battery. The only precautions to be observed are that reasonably good ventilation is provided and that water is added at sufficiently frequent intervals to replace that lost by evaporation.

Trickle charging is also frequently employed to keep batteries supplying intermittent power fully charged. In this case a slightly higher charging rate is employed.

If a trickle charging system is employed to keep an emergency battery fully charged at all times, its operation should be checked periodically until it is certain that the system is not giving too much nor too little charge. If the specific gravity continues to drop, the battery is not receiving enough charge.

There is a widespread impression that a lead-acid battery held ready for emergency should be given periodic cycles of discharge and charge in order to maintain its normal capacity. If such a battery is kept on a trickle charge at the required rate, when not in use, it will be fully charged and capable of delivering its maximum capacity at the normal discharge rate during an emergency.

3–5d. Equalizing Charge—At regular intervals, such as once a week for a battery in daily use, an overcharge at a low rate is desirable to reduce completely the lead sulphate and bring all the cells of the battery up to full charge. This is known as an equalizing charge. Batteries not in daily use require an equalizing charge less frequently.

The equalizing charge should be a continuation of the regular charge and should be carried out at a rate not higher than the charging rate at the completion of the regular charge and lower if possible. It should be continued until no increase in specific gravity or cell voltage is noted in three consecutive readings taken at half-hour intervals.

Although a frequent equalizing charge is desirable and beneficial to a battery, persistent overcharging is very undesirable as it tends to dislodge the active material from the positive plate of the cell.

3–5e. Battery Charging Panel—A small battery charging panel, typical of the type which for many years has been employed on ships for the purpose of charging the 12-volt storage battery associated with low-power emergency transmitters, is shown in Figure 3–12. The double-pole double-throw switch, when thrown to the left, places the batteries on charge directly from the ship's power. The charging current is regulated by fixed resistors on the back of the panel. The switch is thrown to the right to discharge the batteries. The ammeter on the panel indicates the rate of charge and discharge. When the battery is neither on charge nor discharge, the ammeter pointer reads zero at the center of the scale. On the left side of zero, the scale is marked "charge"; on the right side "discharge." When the batteries are placed on charge, and the charging polarity is correct, the meter pointer will move to the "charge" side of the scale. If the polarity is reversed, it will indicate on the "discharge" side, and, in this case, the switch should immediately be opened.

On small charging panels of this type, no protective circuit breakers are provided and the operator is required to take the batteries off charge whenever the ship's generator is shut down. If this is not done, the batteries will discharge through the windings of the generator, possibly resulting in reversal of the polarity of the machine when it is again started.

3–5f. Charging Circuit of RMCA ET–8025 Transmitters—Figure 3–13 shows the circuit arrangement for controlling the charge of the 12-volt emergency storage batteries associated with the Radiomarine Corporation of America Model ET-8025 Radiotelegraph Transmitter. The charging panel includes eight series-connected 1.37-ohm resistors (10.96 ohms total) for the full charging rate of approximately 9 amp. For trickle charging, two parallel-connected 100-ohm resistors (50 ohms total) are connected in series with the 10.96-ohm resistor group. This provides a trickle charging rate of approximately 1.5 amp.

Instructions relating to the maintenance of this battery read as follows:

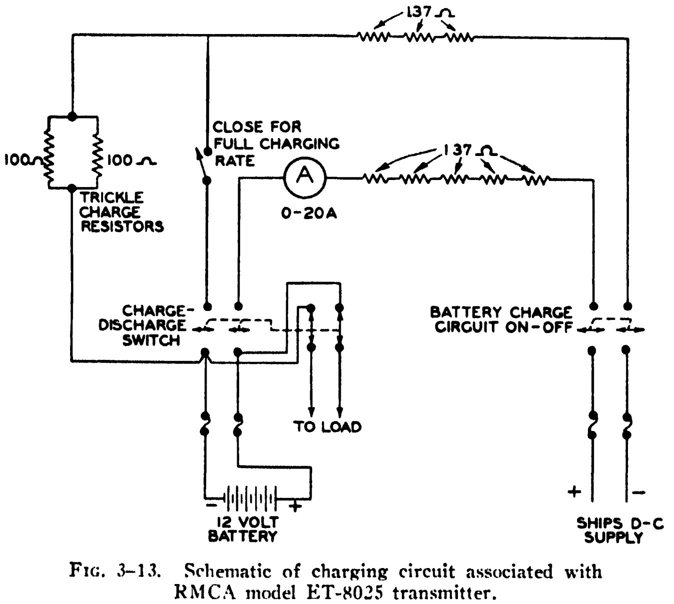


Fig. 3–13. Schematic of charging circuit associated with RMCA model ET-8025 transmitter.

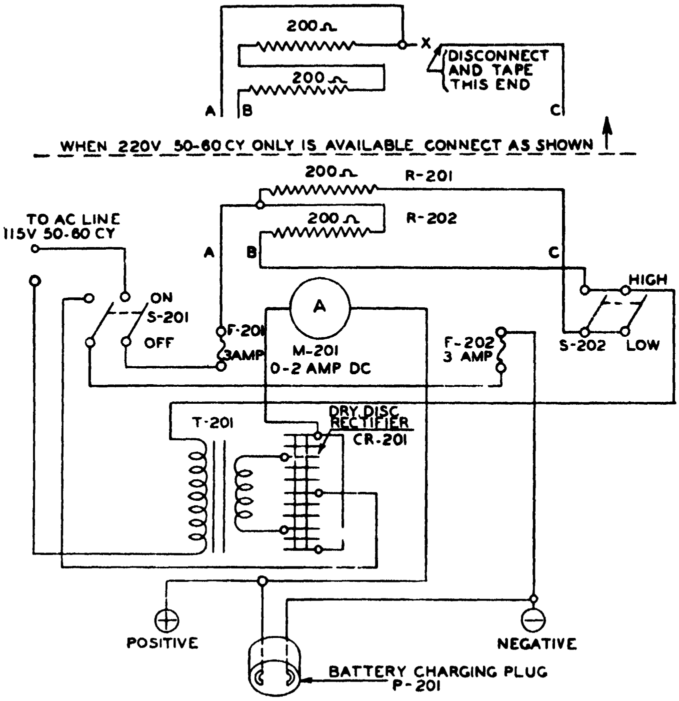


Fig. 3–14. Circuit arrangement of battery charging panel associated with RMCA model ET-8026 portable lifeboat transmitter.

"It is important neither to undercharge nor overcharge the battery. Recommended procedure is to keep the battery on trickle charge while the operator is on duty, as this will minimize the amount of heat dissipated in the radio room. Battery gravity should be checked periodically and the full charging rate used whenever necessary to keep the battery in good condition. Attention of radio operators is directed to section 8.118 of F.C.C. Ship Rules regarding daily tests of emergency storage batteries for polarity and correct charging rate.

When taking gravity readings, use one cell as a pilot cell, selecting a second pilot cell every six months or so in order to equalize any small loss of electrolyte over all six cells.

Exercise great care that the battery is never accidentally discharged. Normally, keep the charge-discharge switch in the CHARGE position unless the ET-8025 transmitter is to be used. This may be done without overcharging the battery, since, if charging is not required the 12 v BAT. CHARGE CIRCUIT switch can be left in the OFF position. Always leave this switch OFF if the vessel lays up, or is in drydock."

CHAPTER 4

THE ELECTRON TUBE

An electron tube consists of a number of electrodes enclosed in a glass or metal enclosure that has been totally or partially evacuated. Two electrodes always present are the cathode, which is an emitter of electrons, and the anode, which is normally operated at a positive potential and attracts the electrons emitted by the cathode. In all but the simplest tubes, there are one or more additional electrodes for controlling the intensity, direction, or speed of the electron flow from anode to cathode.

It is no longer possible to call all radio tubes "vacuum tubes," as we constantly employ rectifiers and control tubes that have had small quantities of gas or metallic vapor added to obtain the required characteristics.

Electron tubes are classified by the number of electrodes they contain. A tube with only two elements is known as a diode, a tube with three electrodes as a triode, and tubes with four and five electrodes as tetrodes and pentodes, respectively.

4-1. Electron Emission—Electron emission is the process by which electrons escape from a material into free space. As has already been explained in Chapter 1, in the atoms of some materials the outermost electrons are not held firmly in place but are free to move from one atom to another. These loosely bound electrons, sometimes called unbound electrons, not only make the conduction of electricity through conductors possible, but also provide the basic requirement of an electron tube—a source of electrons. If sufficient energy is imparted to an unbound electron from an external source, it is possible for the electron to gain sufficient velocity to break through the surface of the material of which it is a part and become a free electron. This is known as *electron emission* and is the process by which free electrons are obtained in the electron tube.

4-2. Types of Emission—The following methods are frequently employed in electron tubes to obtain emission of electrons:

1. Thermal, or *thermionic emission,* wherein the emitting surface is heated to obtain emission of electrons.
2. *Secondary emission,* where energy is imparted to the electrons from high-velocity electrons or ions bombarding the emitting surface.
3. *Photoelectric emission,* where light falling on the emitting surface imparts energy to the unbound electrons, thus causing emission.
4. *Field emission,* which is caused by the influence of a strong electrostatic or electromagnetic field.

Of these methods, thermionic emission, where the emitting surface is heated, is by far the most important and the most frequently encountered in the more common electron tubes employed in radio work.

4-3. Thermionic Emission—When heat is applied to a metal, the movement of its electrons is accelerated. As the temperature is increased, the velocity of the electrons also increases, until a temperature is reached where some of the electrons acquire sufficient velocity to break through the surface of the metal and become free electrons. This is known as thermionic emission and is the most common method used in electron tubes to produce the necessary supply of free electrons. The emission of electrons from the heated metal has often been compared to the evaporation of vapor from heated water.

In escaping from the metal, the electrons must overcome restraining forces which tend to hold them within the metal. The energy to accomplish this comes from the high velocity of the electrons which, in turn, is a result of the heat applied to the metal. Only at relatively high temperatures do any appreciable number of electrons acquire the required velocity to escape through the surface.

4-4. Cathodes—The simplest type of cathode consists of a wire filament of pure metal, usually tungsten, through which a heating current is passed. This is known as a self-heating, self-emitting cathode and was used in all the early electron tubes. This type of cathode is quite inefficient in that very high filament power is required. In addition, considerable difficulty with hum is encountered if this type of cathode is heated from alternating current. Considerable progress has been made in cathode design since this simple filamentary cathode was used exclusively, and present-day cathodes are quite efficient and free from hum.

Cathodes may be divided into two general types, (a) filamentary or directly heated cathode, and (b) the indirectly heated cathode.

4-4a. The Filamentary Cathode—There are two types of filamentary emitters, those of a pure metal such as tungsten, and those of a thoriated metal or an oxide-coated metal, where the thorium or the oxide coating serves to improve the efficiency of emission. The latter types are often called self-heating, coated, emitter-type cathodes.

In the first group, tungsten is most common, although tantalum and molybdenum are occasionally employed. Today, pure metal tungsten filaments will be found only in large high-voltage, transmitting, rectifying, and X-ray tubes where they are used because of their ability to withstand extremely high temperatures and high electric field strengths at their surface. In this type of service, they usually provide a longer life than other types of cathodes. Tungsten is no longer used in smaller tubes operating at medium and low voltages because of the high filament power required.

Thoriated tungsten filaments are made of tungsten to which a small amount of thorium oxide has been added. When properly treated, a layer of thorium about one atom thick is formed on the surface of the tungsten. The presence of the thorium results in an emitter that liberates electrons at much lower temperatures than pure tungsten and therefore requires considerably lower filament power. Thoriated tungsten cathodes are currently used in low- and medium-power transmitting tubes and certain special purpose tubes.

Oxide-coated filamentary cathodes usually consist of a mixture of barium and strontium oxides, or other alkaline-earth compounds, coated on the surface of a nickel alloy wire or ribbon. The ribbon is used when it is desired to increase the area of the emitting surface. Oxide-coated cathodes operate satisfactorily at the relatively low temperature of 700° to 800° C and provide an abundant supply of electrons. These cathodes are commonly used in receiving tubes, rectifiers, and some transmitting tubes.

4-4b. The Indirectly Heated Cathode—The indirectly heated cathode, commonly used in receiving tubes, consists of a cylindrical metal sleeve, the outer surface of which is coated with an electron-emitting material, usually barium and strontium. Inside, and insulated from the metal sleeve, is a tungsten heater which heats the metal sleeve by heat conduction and radiation. Emission takes place from the oxide coating on the metal sleeve. The heater may be operated from either alternating or direct current.

Because there is no electrical connection between the heater and the actual emitter, little difficulty with hum is encountered when operating tubes with indirectly heated cathodes from alternating current. Another advantage of this type of cathode is the fact that a number of tubes may be heated from a single source of power even if a difference of potential exists between the various cathodes. A disadvantage is the time required for heating.

The indirectly heated cathode is sometimes known as the "unipotential cathode" because the entire surface of the cathode is at one potential. This is not true with the filamentary cathode, where a different potential exists at every point along its entire length as a result of the heating-current voltage drop.

4-5. The Vacuum—The cathode is only one electrode in an electron tube. There are others (to be described presently), all of which are enclosed in a glass or metal envelope which is then evacuated. This evacuation is necessary not only to protect the cathode from burning out, but also to remove all gases from the tube. If any gas remains, the operation of the tube will be influenced markedly. During manufacture, many precautions are taken to remove all gas from the tube, including gas from inside the metal of the elements. To aid in the final clearance of gas from the tube, an easily volatilized metal such as magnesium or barium is often employed. This is known as a "getter" and is placed in the tube during assembly. After the vacuum pumps have removed as much gas as possible, the tube is heated. For glass tubes, a high-frequency induction furnace is used, whereas for metal tubes gas flames are employed. The heat drives out gases from within the metal electrodes and also flashes, or vaporizes, the getter. Any gas still within the tube combines with the vapor released by the getter and forms the well-known "silver" coating on the inside of the tube envelope.

Some electron tubes have a small amount of gas added after evacuation. This gas is at an extremely low pressure, far below atmospheric pressure; nevertheless, the presence of this small amount of gas changes completely the characteristics of the tube.

We, therefore, have two basic types of electron tubes—the high-vacuum tube and the gas-filled tube. Inasmuch as high-vacuum tubes constitute the bulk, they will be discussed first. Gas-filled tubes will be described later in this chapter.

4-6. The High-vacuum Diode—The simplest type of vacuum tube is the "diode," so named because it contains two electrodes—a cathode and an anode, or plate. If a battery is connected between the cathode and the plate with the positive side of the battery to the plate, a current will flow through the tube. The strength of this current will depend on the temperature of the cathode and the magnitude of the voltage between plate and cathode. If the connections of the battery are reversed and the negative side of the battery is connected to the plate, no current will flow. The diode, therefore, is a one-way conductor of electricity; it will pass current when the plate is positive with respect to the cathode, but not when the plate is negative with respect to the cathode.

This one-way action can be explained by considering what takes place within the diode. The heated cathode is liberating free electrons. When a positive voltage is applied to the plate, the electrons, being negative, are attracted to the plate. Upon reaching the plate, the electrons enter it and continue through the external tube circuit back to the cathode, thereby constituting the flow of plate current. When the polarity of the battery is reversed, a negative voltage is applied to the plate. This negative charge repels electrons leaving the cathode and none reach the plate. Current, therefore, does not flow.

4–6a. Saturation Current and Space Charge—In diode tubes, no plate current flows when the plate is at negative potential since the electrons emitted by the cathode are repelled. When the plate is at a very high positive potential, the plate attracts all the electrons that are emitted by the cathode. This is known as *saturation current.* Under these circumstances, increases in plate voltage result in little or no increase in plate current because the cathode is not capable of supplying any additional electrons.

Between these two extremes, at normal values of plate voltage not all the electrons emitted by the cathode are attracted to the plate. The negative charge of the electrons already in transit from cathode to plate tend to repel other electrons which leave the cathode after them. These electrons remain in the space between the cathode and plate momentarily and then return to the cathode. The combined charge of these electrons surrounding the cathode results in a negative charge which tends to neutralize the positive attraction of the plate upon electrons just leaving the cathode. This negative charge, which limits the plate current, is known as *space charge.*

4–6b. Characteristics of High-vacuum Diode—If the diode is connected as shown in Figure 4–1, measurements can be made of the plate current at various values of plate voltage and cathode temperature. When these measurements are plotted, the resulting curves are known as the tube's plate-voltage plate-current characteristics. The curves shown in Figure 4–1, which are for a typical, small diode tube, were made with three different values of heater voltage.

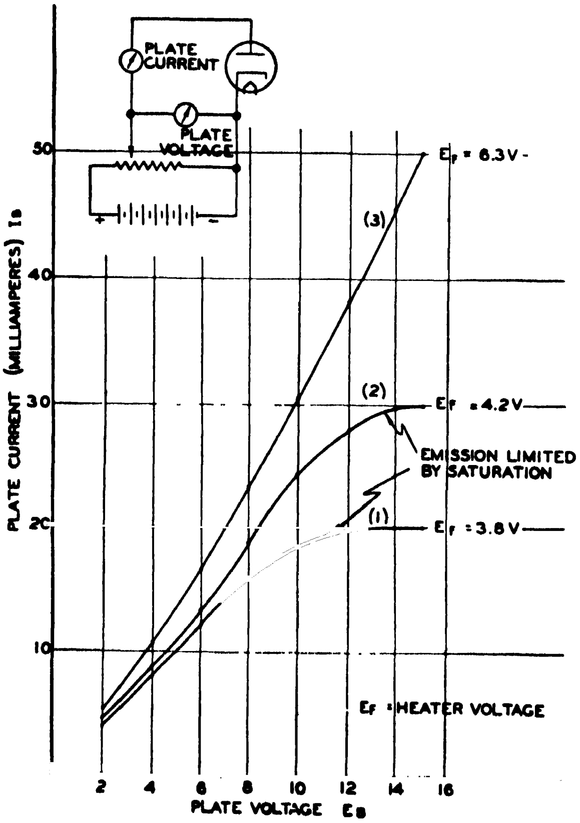


Fig. 4–1. Typical plate-voltage plate-current characteristics of high-vacuum diode.

At the lowest value of heater voltage (curve 1) it will be noted that 12 volts were sufficient to cause saturation, that is, voltage greater than 12 volts caused no further increase in plate current. In curve 2, which was made at a higher heater voltage, saturation occurred at a plate voltage of 14; in curve 3, with the tube operating at its rated heater voltage, saturation had not yet been reached at the highest voltage measured.

4–6c. Rectification of A.C. by a High-vacuum Diode—In radio work, the most common use of the diode is in connection with the rectification of alternating current. Its operation, with a.c. applied between plate and cathode, is shown graphically in Figure 4–2.

The alternating voltage causes the anode to become alternately positive and then negative with respect to the cathode. Current flows through the diode only during the half cycles when the anode is positive. The diode, therefore, passes a series of half-cycle pulses known as *rectified current.*

4–6d. Uses of High-vacuum Diodes—Diodes are widely used in the power supplies of radio receivers and transmitters to rectify alternating current. Many different types and sizes of tubes are available for this purpose, the principal differences being the voltage and current capabilities of the tubes. Many tubes that rectify contain two separate diode elements—two plates and two cathodes. These tubes, known as *duo-diodes,* operate in "full-wave" rectifier systems in which two diodes operate alternately to pass alternate half-cycles of the supply current. Such full-wave circuits result in greater efficiency and greater ease in smoothing, or filtering, the resulting output pulses.

Diodes also are commonly used as detectors, or demodulators, in present-day radio receivers. In this application, the alternating current to the diode is of radio frequency and of very low power; hence, a small diode suffices. If Figure 4–2 is examined carefully, it will be noted that the output half cycles are not exactly the same shape as the input half cycles that produced them. This is because the plate-current plate-voltage curve is not a straight line. Nonlinearity, as this is known, results in distortion. Although some nonlinearity is present in the diode, improvement can be obtained in a properly designed detector circuit. The diode detector can handle very strong signals without overloading and is probably more widely used than any other type of detector.

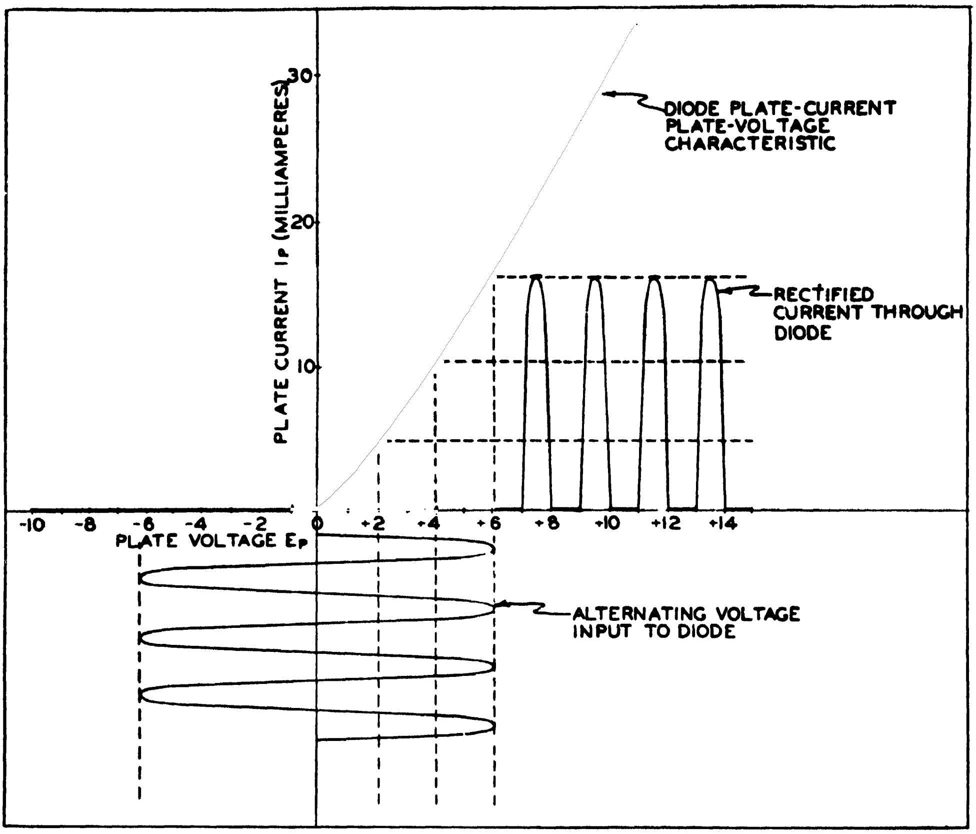


PLATE CURRENT I_P (MILLIAMPERES)
30
20
10
DIODE PLATE-CURRENT PLATE-VOLTAGE CHARACTERISTIC
RECTIFIED CURRENT THROUGH DIODE
-10 -8 -6 -4 -2 0 +2 +4 +6 +8 +10 +12 +14
PLATE VOLTAGE E_P
ALTERNATING VOLTAGE INPUT TO DIODE

FIG. 4–2. Rectification of alternating current in a high-vacuum diode.

4–7. The High-vacuum Triode—A triode is a three-electrode tube containing an anode, a cathode, and a control electrode commonly known as a *grid*, or *control grid*. The addition of the grid results in an extremely sensitive device which may be used as an amplifier, as well as a very sensitive detector of radio signals.

In the diode, it has been seen that a change in plate voltage will result in a change of plate current. Lee De Forest, who invented the three-element tube, found that this change could be produced much more easily by keeping the plate voltage unchanged and instead changing the voltage of a third electrode, which he called the grid, located in the space between the anode and cathode. The grid in present-day electron tubes is usually a winding of wire, extending the full length of the cathode, with relatively large spaces between the turns in order that the flow of electrons from cathode to plate will not be obstructed. It is normally operated at a negative potential and therefore attracts no electrons. The purpose of the grid is to control the flow of plate current.

The effect of grid voltage, compared to plate voltage, on the plate current of a typical triode can be determined from Figure 4–3, which shows the plate voltage and plate current characteristics of a typical, small, receiving triode for three values of grid voltage. With a plate voltage of 180 volts and a grid voltage of −4, a plate current of 10 ma (milliamperes) flows through the tube. If it is desired to reduce the current to 5 ma, this can be done by reducing the plate voltage to 140 volts, leaving the grid voltage unchanged. On the other hand, if the plate voltage is left at 180 volts and the grid voltage increased to −6 volts, the plate current will again be reduced to 5 ma. Thus, the same effect is produced in this tube by either changing the plate voltage 40 volts or changing the grid voltage only 2 volts—one-twentieth as much. The grid voltage is, therefore, much more effective in controlling the current through the tube than the plate voltage—in the above example 20 times as much. This is known as amplification, the amplification in this case being 20.

It should be noted that, as long as the grid is kept negative, it repels electrons and no current flows in the grid circuit. Thus, no power is consumed in the grid circuit, although actual power is controlled in the plate circuit. However, if the grid is permitted to become positive with respect to the cathode, electrons are attracted to it. Under these conditions, grid current flows and power is consumed in the grid circuit.

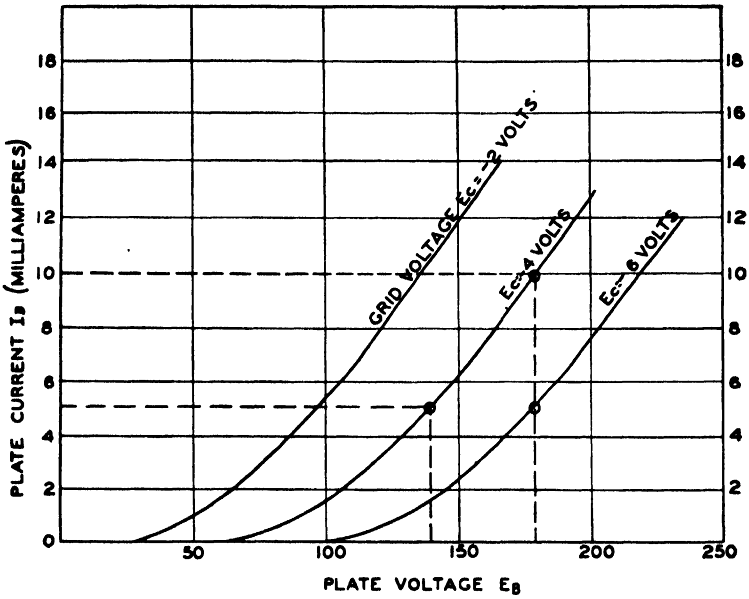


FIG. 4–3. Plate-voltage plate-current characteristics of a typical receiving-type triode.

4–7a. Parameters of High-vacuum Triodes—The three important characteristics, or "parameters," of a triode (as well as other high-vacuum tubes to be described later) are (1) amplification factor μ, (2) dynamic plate resistance r_p, and (3) transconductance G_m.

1. *Amplification Factor.* The amplification factor of a vacuum tube is an expression of the relative effect of grid voltage and plate voltage on the plate current and may be defined as *the ratio of a small plate voltage change to the grid voltage change which will produce the same change in plate current.*

The amplification factor is a statement of the amplifying ability of the tube. Commonly used triodes exhibit amplification factors ranging from 2 to 100. The amplification factor of a tube depends on the shape and spacing of the electrodes. A closely wound grid or a grid wound of large wire tends to increase the amplification factor of a tube.

If the letter *d* is used to symbolize the phrase "a small change in," e_p to represent plate voltage, e_g grid voltage, and i_p plate current, then amplification factor can be expressed as follows:

$$\mu = \frac{de_p}{de_g} \text{ (for constant } i_p\text{)}$$

2. *Dynamic Plate Resistance.* The plate-cathode circuit of a vacuum tube offers resistance to the flow of plate current through the tube. This resistance is usually expressed as the *dynamic plate resistance* of the tube. The dynamic plate resistance, sometimes called a-c plate resistance, of a vacuum tube may be defined as *the ratio of a small change in plate voltage to the small change in plate current which it produces.* The grid voltage of the tube is to be maintained at a constant value. The dynamic plate resistance is expressed in ohms and ranges from 800 to 100,000 ohms in commonly used triodes. Using the same symbols as above, plate resistance can be expressed as follows:

$$r_p = \frac{de_p}{di_p} \text{ (with } e_g \text{ constant)}$$

The dynamic plate resistance depends to a large extent on the structure of the tube. Tubes with low amplification factors have relatively low plate resistance, whereas tubes with high amplification factors have relatively high plate resistance.

3. *Transconductance.* The transconductance of a vacuum tube (sometimes called mutual conductance) is an expression of the relationship between the grid voltage and the plate current and may be defined as *the ratio of a small change in plate current to the small change in grid voltage that produces it.* The plate voltage of the tube is to be maintained constant. Again employing the same symbols as above, transconductance can be expressed as follows:

$$G_m = \frac{di_p}{de_g} \text{ (with } e_p \text{ constant)}$$

Transconductance is expressed in *mhos* (the unit of conductance), but, since the values encountered in vacuum tubes are small, the unit *micromho* (one millionth of a mho) is usually employed. Triodes in common use exhibit a transconductance ranging from 500 to 5000 micromhos.

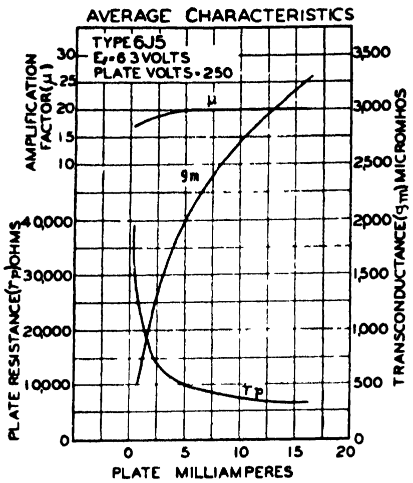


FIG. 4–4. Values of amplification factor, plate resistance, and transconductance of a receiving type triode as a function of plate current. (Courtesy RCA.)

4–7b. Relationships between G_m, r_p, and μ—A simple relationship exists between transconductance, plate resistance, and amplification factor that makes it possible to find any one quantity if the other two are known. The relationships are:

$$\text{Amplification factor } \mu = r_p \times G_m$$

$$\text{Dynamic plate resistance } r_p = \frac{\mu}{G_m}$$

$$\text{Transconductance } G_m = \frac{\mu}{r_p}$$

The amplification factor, plate resistance, and transconductance of a tube do not remain constant under all conditions but change as the electrode voltages and plate current of the tube are changed, or when very large signals are being handled. The values given by the manufacturer are usually stated along with the recommended operating voltages and hold true only when the tube is operated at these values. Figure 4–4 shows in graph form the change in amplification factor, dynamic plate resistance, and transconductance as a function of plate current for a small, receiving-type triode.

4–7c. Characteristic Curves of High-vacuum Triode—If a triode is connected as shown in Figure 4–5, measurements of its plate voltage, plate current, and grid voltage can be made. These values are usually plotted in one or both of the following forms: (1) plate-current versus plate-voltage with constant values of grid voltage, and (2) plate-current versus grid-voltage with constant values of plate voltage. The former is usually known as a tube's plate characteristic and the latter as a tube's transfer characteristic. Curves of this

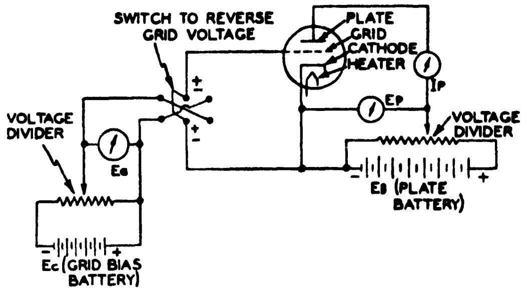


FIG. 4–5. Circuit for measuring the static characteristics of a triode.

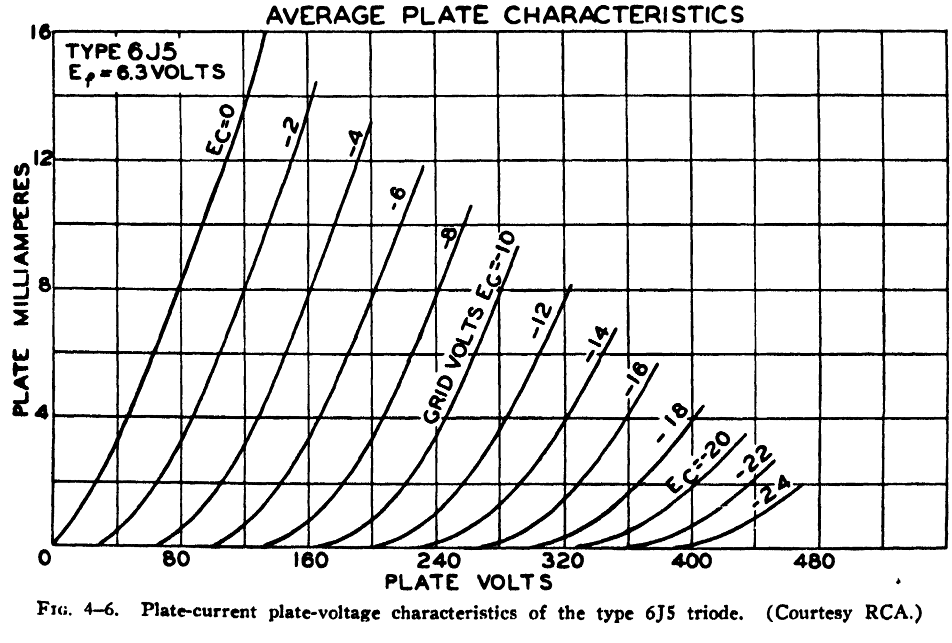


FIG. 4–6. Plate-current plate-voltage characteristics of the type 6J5 triode. (Courtesy RCA.)

nature are known as the tubes *static* characteristics. Examples of each type of curve for a typical receiving triode are shown in Figure 4–6 and Figure 4–7.

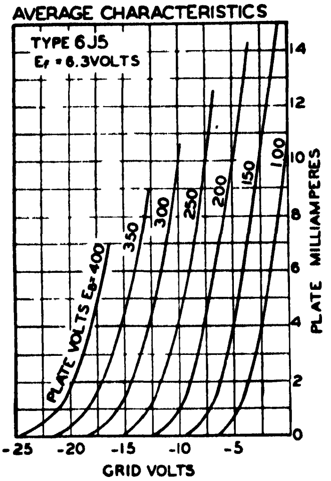


Fig. 4–7. Plate-current grid-voltage characteristic of the 6J5 receiving-type triode. (Courtesy RCA.)

The triode characteristics plotted in Figures 4–6 and 4–7 were made in the tube's operating range where the plate current was limited only by space charge, that is, saturation current due to lack of emission had not yet occurred. If the measurement had been made at a lower than normal value of heater voltage or had the measurements been extended to greater values of plate current, saturation would be evident by the curves flattening off at high values of plate current.

4–7d. A-C Signal Input—A vacuum tube is normally operated with a fixed d-c voltage applied between cathode and grid, known as *grid bias*, upon which a signal voltage E_g is superimposed. The fluctuations of the signal voltage cause the actual grid voltage to swing alternately positive and negative with respect to the grid bias voltage. Figure 4–8 is a curve illustrating a tube's operation under these conditions. The tube is operating with a grid bias voltage of —6 volts, which results in a plate current of 12 ma. Superimposed on the grid bias voltage is a sine wave signal voltage with a peak value of 4 volts. This signal voltage results in the grid voltage swinging 4 volts above and 4 volts below the bias voltage or from — 2 to — 10 volts. The plate current flowing through the tube as a result of this grid voltage varies from 20 to 4 ma.

It will be noted that the grid voltage swing is confined to the linear portion of the tube's grid voltage-plate current characteristic. This is essential if undistorted amplification is desired. Should the grid swing be slightly greater than shown, it would enter upon the nonlinear portions at each end of the

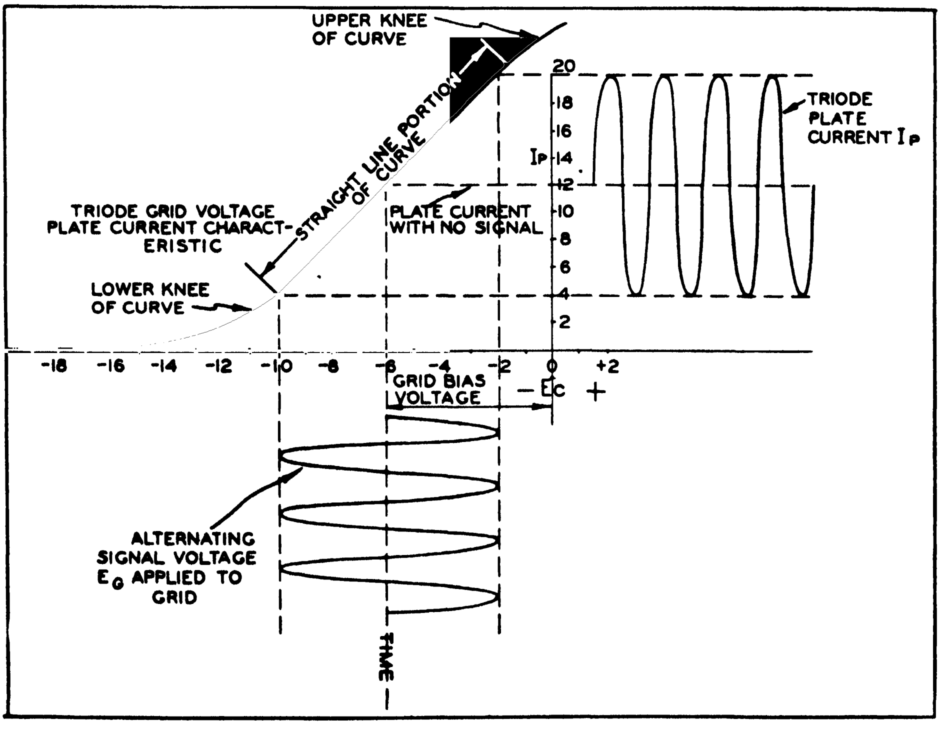

UPPER KNEE OF CURVE
STRAIGHT LINE PORTION OF CURVE
TRIODE GRID VOLTAGE PLATE CURRENT CHARACT-ERISTIC
LOWER KNEE OF CURVE
PLATE CURRENT WITH NO SIGNAL
TRIODE PLATE CURRENT I_P
20
18
16
14
12
10
8
6
4
2
I_P
-18
-16
-14
-12
-10
-8
-6
-4
-2
0
+2
GRID BIAS VOLTAGE
— E_C +
ALTERNATING SIGNAL VOLTAGE E_G APPLIED TO GRID
TIME

Fig. 4–8. Operation of a triode with an alternating voltage applied to the grid.

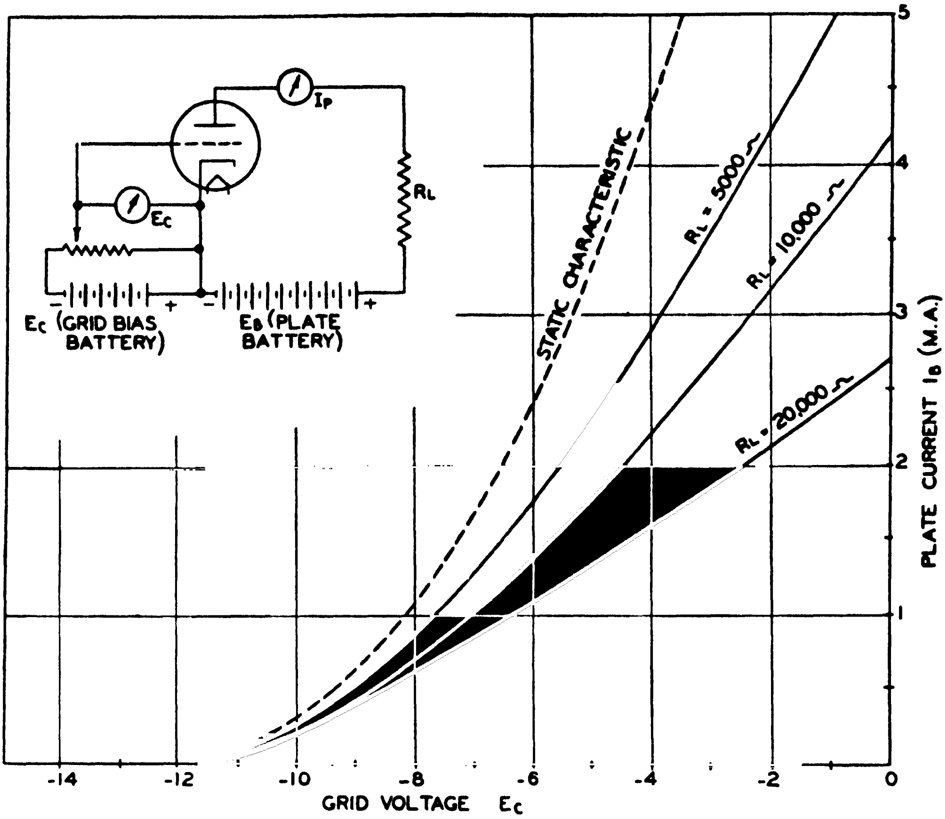


Fig. 4–9. The dynamic characteristics of a typical receiving-type triode with three different values of load resistance.

curve. At these points the plate current would not change linearly with respect to the grid voltage, and the plate current fluctuations would no longer be an accurate reproduction of the signal voltage. There are special cases where the signal voltage is purposely allowed to swing on the curved portions of the tube's curve. This is usually done in triode plate detection and in certain classes of amplification, both of which are discussed later.

4–7e. Plate Load—To obtain any useful output from a vacuum tube, it is necessary to connect a load in the plate circuit. The full plate current of the tube flows through this load and, consequently, there is a voltage drop across it, which results in a voltage lower than the battery voltage actually reaching the plate of the tube. In addition, the added resistance in the plate circuit results in a lower value of plate current than indicated on the tube's static characteristic curves, which are made with no load in the plate circuit.

Characteristic curves may be made with a load resistor connected in the tube's plate circuit. When this is done, the resulting curve is known as the tube's *dynamic* characteristic. A dynamic characteristic, showing grid-voltage plate-current relationships of a small triode tube with three different values of load resistance, is given in Figure 4–9.

If an a-c signal voltage, superimposed upon the grid bias battery voltage, is applied to the grid of a tube with a load resistor in its plate circuit, such as shown in Figure 4–10, the plate voltage will be affected in the following manner. During the positive half cycle of the signal voltage E_g, the grid voltage becomes less negative and the plate current through the tube increases. The increased plate current causes an increase in the voltage drop across the load resistor, and the voltage at the plate of the tube decreases (by an amount equal to the increase in voltage drop across the load resistor).

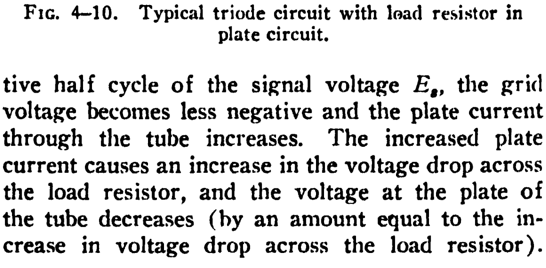


Fig. 4–10. Typical triode circuit with load resistor in plate circuit.

During the next half cycle, which is negative, the grid becomes more negative and the plate current of the tube decreases. The voltage drop across the load resistor also decreases, and the voltage at the plate of the tube therefore increases (by an amount equal to the decrease in the voltage drop across the load resistor). The sum of the voltage drop across the load resistor and the plate voltage across the tube must always be equal to the battery voltage.

As a result of the above discussion, the following statements can be made:

1. As the grid voltage becomes less negative (positive swing of signal voltage), the plate current will increase, the voltage drop across the load resistor will increase, and the plate voltage will decrease.
2. As the grid voltage becomes more negative (negative swing of signal voltage), the plate current will decrease, the voltage drop across the load resistor will decrease, and the plate voltage will increase.

It should be understood that, unless a signal voltage of extremely low frequency is involved, the milliammeter in the plate circuit is unable to follow the fluctuations in plate current. It will continue, therefore, to read the normal, no-signal plate current, as long as the signal voltage remains on the linear portion of the tube's characteristic curve. The plate current, however, is actually swinging up and down with respect to the normal plate current, in accordance with the fluctuations of the signal voltage.

4–7f. Phase Reversal—In a vacuum tube the signal voltage is applied between the grid and cathode, and the output voltage is obtained between plate and cathode. It has already been shown that a positive half cycle of signal voltage results in a decrease of plate voltage, whereas a negative half cycle of signal voltage results in an increase of plate voltage. Therefore, when the signal voltage increases, the output voltage decreases and vice-versa. This is known as *phase reversal* in a vacuum tube and becomes quite important in some vacuum tube amplifiers, especially in certain types of push-pull amplifiers where a vacuum tube is employed to shift the phase 180° in order to obtain the proper polarity of exciting voltage.

4–7g. Voltage Amplifiers and Power Amplifiers—Vacuum tubes are usually designed to fulfill one of two purposes: to provide voltage amplification or to provide power amplification. Voltage amplifiers are used when high amplification of a signal voltage is desired. As voltage amplification is the only requirement, the plate current of the tube may be relatively low, thereby permitting the use of a small tube with a relatively small cathode. When the greatest possible voltage amplification is desired, a tube with a high amplification factor is usually used.

Power amplifiers are used when the signal voltage is to be converted into power. The output of a power amplifier must deliver, therefore, both high voltage and high current. The cathode of a power amplifier must be large and capable of supplying sufficient emission for the large plate currents. Such cathodes require large heating currents. The plate and grid of the power amplifier must be capable of operation under these conditions without overheating.

4–7h. Interelectrode Capacitances—Each electrode of a vacuum tube forms one plate of a very small condenser which exists between it and each other electrode in the tube. Although these capacitances are very small, they often assume great importance, sufficient in some instances to prevent a tube from operating satisfactorily. In a triode tube, three different capacitances exist, the grid-cathode capacitance, C_{gk}, the plate-cathode capacitance, C_{pk}, and the plate-grid capacitance, C_{gp}. Still other capacitances exist in tubes with more than three electrodes.

The grid-plate capacitance is particularly troublesome in many instances. It has been shown in Chapter 1 that a condenser has the ability to pass an alternating current. Therefore, with this grid-plate capacitance present, the grid circuit is not entirely independent of the plate circuit. Signals in the plate circuit can be *fed back* to the grid circuit though the interelectrode capacity of the tube. In some applications, this interelectrode feedback can result in very unstable operation, at times to the extent of causing the circuit to generate sustained oscillations. In fact, one type of oscillator circuit (the tuned grid-tuned plate) depends on the internal feedback through the grid-plate capacitance of the tube for its operation. Although this condition may be satisfactory in the design of some types of oscillators, it is very undesirable in the design of high-gain amplifiers, particularly those with tuned circuits in the grid and plate circuits. Neutralization[1] of the feedback voltage has often been resorted to in order to overcome this difficulty, but the addition of another electrode to the tube, to act as an electrostatic shield between plate and grid is far more satisfactory and permits much greater gain to be realized in each stage of amplification.

4–8. The High-vacuum Tetrode—The tetrode, or screen grid tube, is essentially a triode to which a fourth electrode, called the *screen grid*, has been added. The physical construction of the screen grid is similar to the control grid and it is mounted within the tube in the space between the control grid and the plate. It is normally operated at a positive d-c potential with respect to the cathode as shown in Figure 4–11. The screen grid acts as an electrostatic shield between the control grid and plate and is very effective in reducing the grid-plate capacitance, often to a value hundreds of times lower than that of a similar triode. This reduction of grid-plate capacitance when using a tetrode makes it possible to realize large values of amplification without difficulty from instability.

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[1] See Section 4–17.

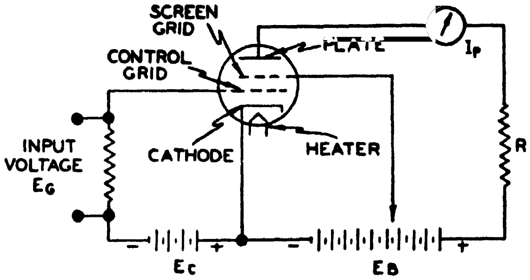


Fig. 4–11. Circuit arrangement of typical tetrode.

At the same time, the tetrode offers another advantage: it provides a higher amplification factor than the triode. This is brought about in the following manner. The screen grid is operated at a positive potential with respect to the cathode, but at a lower positive potential than the plate. It, therefore, attracts electrons from the cathode although most of these electrons, upon reaching the screen grid, pass through the open mesh of the screen and on to the more positive plate. However, electrons in the space between the cathode and screen grid are more under the influence of the positive charge on the screen than the positive charge on the more distant plate. Because of the presence of the screen grid, the plate has become less effective in attracting electrons from the cathode than it would be if the screen were not present. Changes in plate voltage, therefore, are less effective in controlling plate current, although the effectiveness of the grid in controlling plate current remains unchanged. Inasmuch as amplification factor is a ratio of the effectiveness of the plate voltage to grid voltage in controlling plate current, it can be seen that the amplification factor of the tetrode will be high. The tetrode, therefore, is a tube which gives a large amount of amplification and at the same time is capable of handling it without instability because of its low grid-plate capacitance.

4–8a. Secondary Emission—One serious disadvantage of the tetrode is the fact that secondary emission of electrons takes place from the plate. This is due to the bombardment of the plate by the stream of electrons from the cathode which results in the dislodgement of some electrons from the surface of the plate. Secondary emission takes place in all electron tubes to a certain extent, but in the case of diodes and triodes these dislodged electrons are immediately drawn back to the plate as there is no other positively charged electrode present in the tube to attract them. In the tetrode, however, the positive charge on the near-by screen grid offers a strong attraction to these electrons and many are attracted to the screen grid. This is particularly true if the plate voltage swings lower than the screen voltage during normal operation. It is usually necessary, therefore, to restrict the plate voltage swing in the tetrode tube as operation becomes quite unstable at low values of plate voltage. This can be seen in the characteristic curves of the tetrode.

4–8b. Characteristic Curves of the Tetrode—The plate voltage-plate current characteristics of a typical tetrode are shown in Figure 4–12. It can be seen that the general characteristics are similar to the triode with the exception of the slope of the curves and the dip in plate current at low values of plate voltage. The flatness of the curves indicates that the plate voltage has very small effect on the plate current, and that the dynamic plate resistance of the tube is therefore high. The dip in plate current is due to secondary emission and occurs at low values of plate voltage where the screen grid voltage exceeds the plate voltage. The characteristics of the tetrode, like the triode, can be expressed in terms of the three parameters—amplification factor, dynamic plate resistance, and transconductance. In general, the tetrodes exhibit high amplification factor, high dynamic plate resistance, and average values of transconductance.

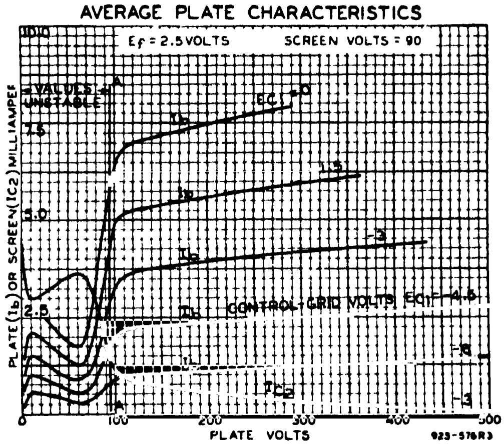


Fig. 4–12. Plate characteristics of the type 24-A tetrode. (Courtesy RCA.)

The tetrode, with the exception of a very special case employing beam construction described below, is no longer in common use because of its limitations resulting from secondary emission. These difficulties have been overcome in the pentode tube in which a shield is placed between the screen grid and the plate to reduce secondary emission effects. Inasmuch as the pentode tube retains all the advantages of the tetrode and overcomes its one disadvantage, it is almost always used where a tube with the tetrode's characteristics is required.

4–9. The High-vacuum Pentode—The pentode is an electron tube with five electrodes, four the same as the tetrode, the fifth being a grid placed between the screen grid and plate and called the *suppressor grid.* This results in a total of three grids in the pentode: the control grid, the screen grid, and the suppressor grid. The purpose of the suppressor grid, as its name implies, is to suppress electrons dislodged from the plate because of secondary emission from reaching the screen grid.

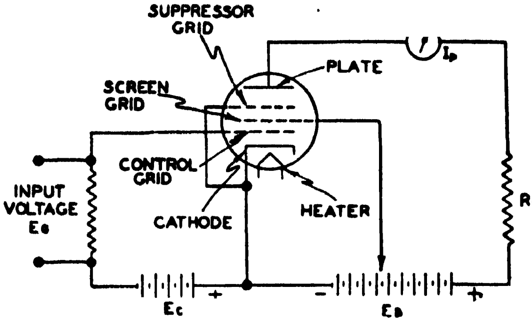


FIG. 4–13. Circuit arrangement of typical pentode.

The suppressor grid is usually connected directly to the cathode as shown in Figure 4–13. In some pentodes they are permanently connected internally, whereas in others the suppressor is brought out to a separate pin terminal in which case the connection to cathode may be made at the socket or, if desired, the suppressor may be used in other ways for special applications. The potential of the suppressor grid is zero with respect to the cathode and, accordingly, negative with respect to the screen grid and plate. Electrons dislodged from the plate as a result of secondary emission will be repelled by this negative electrode and be forced back to the plate.

4–9a. Characteristic Curves of the Pentode—The characteristic curves of the pentode are very similar to the tetrode with the exception that the dip in plate current at low values of plate voltage caused by secondary emission does not occur. The plate voltage-plate current curve of a typical pentode is shown in Figure 4–14.

The additional grid between control grid and plate serves to shield these two electrodes from each other still further. As a result the grid-plate capacitance is even lower, and the amplification factor and dynamic plate resistance are even greater, than those in the tetrode. The plate-voltage swing can be made large compared with the tetrode because of the absence of secondary emission difficulties.

The three triode parameters—amplification factor, dynamic plate resistance, and transconductance—also express the characteristics of the pentode and are used in the same manner as for the triode. In general, pentodes, like tetrodes, exhibit high values of amplification factor, high values of dynamic plate resistance, and average values of transconductance.

4–10. Beam Power Tubes—The beam power tube is a special type of tetrode which, because of its design, operates in a manner comparable to a pentode in that secondary emission is effectively suppressed even though a suppressor grid is not used. The beam power tube derives its name from the beam-forming plates which are employed to direct the flow of electrons from the cathode to plate into beams as shown in Figure 4–15. The beam-forming plates are connected to the cathode within the tube and therefore operate at cathode potential.

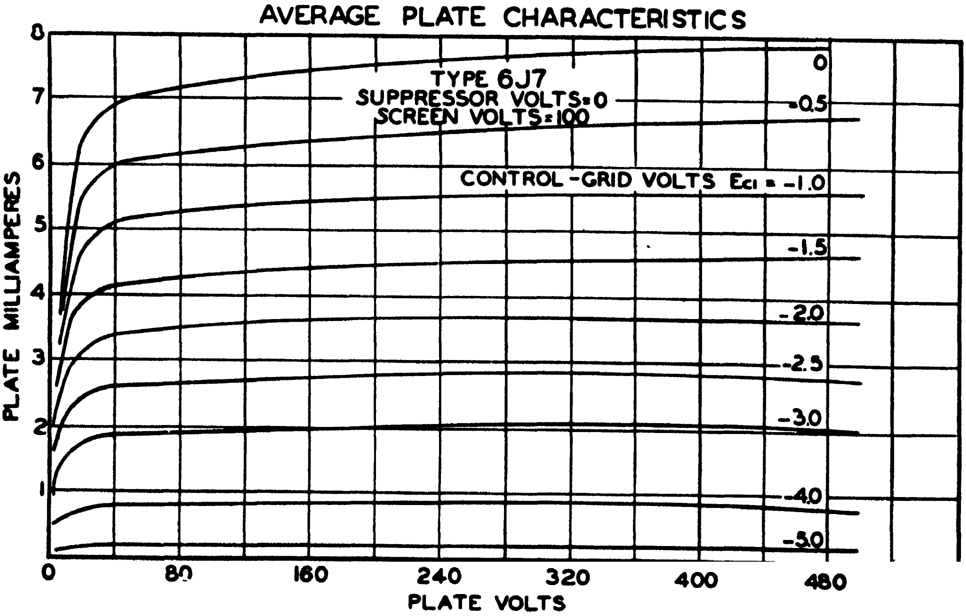


FIG. 4–14. Plate characteristic of the type 6J7 pentode. (Courtesy RCA.)

In the beam power tube, the screen grid is operated at a positive potential equal to, or slightly exceeding, the plate voltage. Electrons traveling from cathode to plate are slowed down in the space between screen grid and plate because of the high positive potential on the screen grid tending to pull them back. The slowing down of these electrons results in the production of a space charge effect between the screen grid and plate. This space charge, being negative, has the same effect on secondary emission as an actual suppressor grid and for that reason the region of high space charge is known as a *virtual suppressor* grid. The suppressor action of this virtual suppressor is much more effective than an actual suppressor grid since the negative suppressing field is continuous as contrasted to the spaced field which results when a wire grid structure is employed.

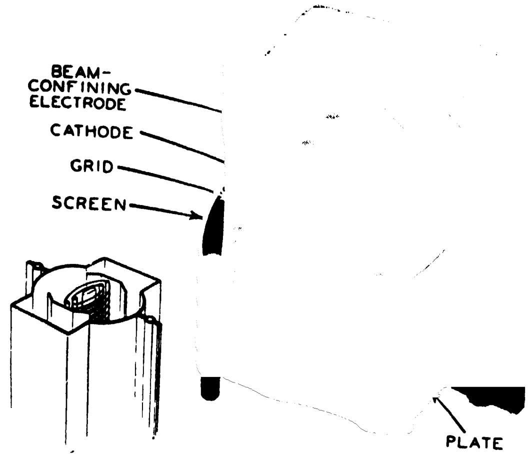


Fig. 4–15. Internal structure of the 6L6 beam power tube. (Courtesy RCA.)

Screen current in the beam power tube is kept low because the control grid and screen grid are aligned in such a manner that each turn of the screen grid is shaded from the cathode by a turn of the control grid. This alignment of control and screen grid results in the electrons passing in layers through the turns of the screen grid, as illustrated in Figure 4–15. This results in very few electrons being attracted to the screen grid and, consequently, a low value of screen current.

Not all beam power tubes are tetrodes, such as described above, some having an actual suppressor grid. These tubes are, therefore, beam power pentodes; those without a suppressor grid are beam power tetrodes

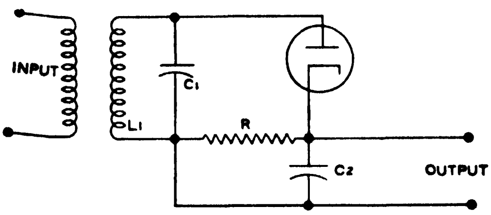


Fig. 4–17. The diode detector.

4–11. The Diode Detector—The high-vacuum diode, Figure 4–17, is the most commonly used detector (demodulator) in present-day radio receivers. The output of the diode detector, when an unmodulated radio-frequency current is applied, is a series

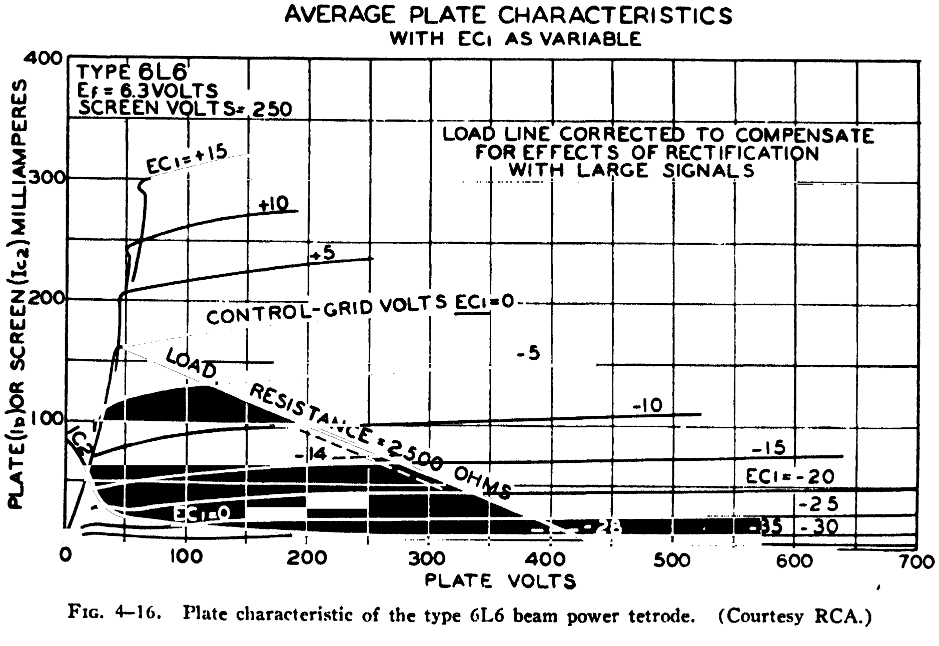


Fig. 4–16. Plate characteristic of the type 6L6 beam power tetrode. (Courtesy RCA.)

of positive half-cycles. These are passed through a small, smoothing filter from which an unvarying direct current emerges that, when passed through headphones, represents no sound at all. If the transmitting station now modulates its output by means of voice, music, or tone, we no longer have an unvarying d-c output from the diode but rather a pulsating direct current in which the pulsations follow the variations of the voice, music, or tone. These variations can be heard by means of a headset in the diode output circuit, or they can be fed to an audio amplifier, which is described later.

The diode is a reasonably high-fidelity detector, even for strong signals, but it does not provide any amplification. It should be noted that the smoothing filter in the output must not be too large or it will also smooth out the audio-frequency output, thus destroying its usefulness.

4-12. The Triode Detector—Two distinct types of triode detectors are frequently employed, although the diode is in much more common use.

4-12a. The Gridleak Detector—The older, more sensitive, but more easily overloaded and more subject to distortion, is the gridleak detector which is shown in Figure 4-18. Whether the gridleak detector employs the filament type of tube shown or an indirectly heated cathode is not significant. In either case there is no grid bias until a signal arrives, hence the plate current must be kept at a low value by using a tube with a fine mesh grid (high mu) or by using a very low value of plate voltage.

The operation of this detector depends on the presence of the grid-blocking condenser C_2, and the high-resistance (several million ohms) gridleak resistor *R*. The latter may be connected either as shown or directly from grid to cathode. In either case the function of the combination is to permit trapping electrons on the grid of the tube, whereupon there occurs a slow leaking off of these electrons through *R* to the cathode. The action is as follows:

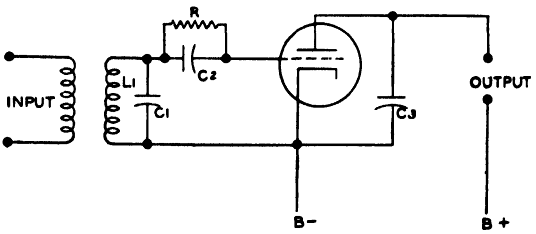


Fig. 4-18. The grid leak detector.

When an unmodulated radio carrier is received, the voltage produced in the tuned circuit L_1 C_1, is applied to the grid through grid condenser C_2, which does not obstruct the passage of such high frequencies. Thus the grid swings at radio frequency and, at each swing in the positive direction, a few electrons are attracted from the space current. Within a very few swings (certainly less than 1/100,000 of a second) enough electrons are trapped on the grid so as to charge it negatively to the same voltage as that of the incoming carrier after which electrons are accumulated by the grid only as fast as the old ones escape toward the cathode through the gridleak. This produces a d-c grid bias, the magnitude of

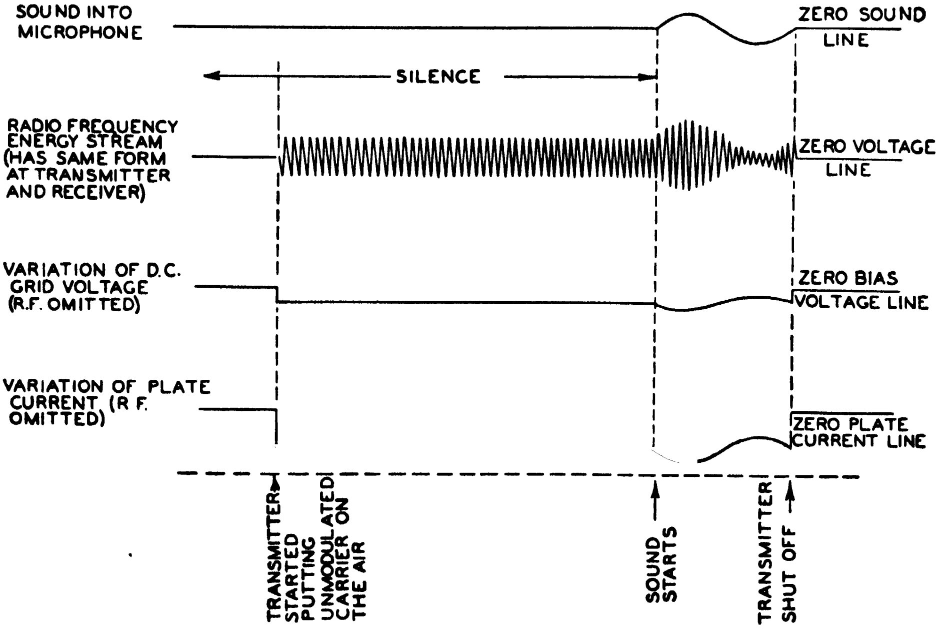

SOUND INTO MICROPHONE
ZERO SOUND LINE
SILENCE
RADIO FREQUENCY ENERGY STREAM (HAS SAME FORM AT TRANSMITTER AND RECEIVER)
ZERO VOLTAGE LINE
VARIATION OF D.C. GRID VOLTAGE (R.F. OMITTED)
ZERO BIAS VOLTAGE LINE
VARIATION OF PLATE CURRENT (R F. OMITTED)
ZERO PLATE CURRENT LINE
TRANSMITTER STARTED PUTTING UNMODULATED CARRIER ON THE AIR
SOUND STARTS
TRANSMITTER SHUT OFF

Fig. 4-19. Grid leak detector action.

which depends on the strength of the incoming carrier, and which reduces the detector plate current in proportion to the strength of that carrier.

Now if modulation of the carrier occurs, it follows that whenever the carrier becomes stronger the grid will swing more widely and at once (within perhaps 1/100,000 second again) will charge itself up to this new level and thus still further reduce the plate current. Similarly, when the carrier is modulated downward (has its voltage lowered), the grid will swing less widely, therefore fail to pick up electrons and presently gridleak resistor *R* will leak it down to this new carrier value, allowing the plate current to rise. Thus the average plate current varies up and down (but in reverse direction) with the sounds at the transmitting station's microphone, and these sounds may be heard by a headset in the detector plate circuit or fed to an audio amplifier. For reasons which shall not be discussed here this type of detection is subject to more difficulties than the diode type or the biased triode type. Hence it is used only where its greater sensitivity is required.

Satisfactory gridleak detection requires that C_2 be large enough to pass the radio frequency readily, but not large enough to pass high audio frequencies, that *R* leak off the grid-charge fast enough to permit following high audio-frequency variations, but not so fast as to reduce sensitivity; and that C_3 (often supplemented by an r-f choke coil) be of a size small enough to prevent by-passing the high audio frequencies in the output, but still adequate to return to the cathode such amplified r.f. as appears in the plate circuit—that is the plate by-pass condenser must short-circuit the r.f. but pass the audio to the headphones or amplifier. In practice this results in a 2 to 5 megohm gridleak *R*, a plate circuit by-pass condenser of about 0.0001 μf and about 2½ times that if music is not to be received, and also a grid condenser of about the same size. For high-frequency receivers both condensers may be smaller.

4-12b. The Bias or Plate Detector—The bias type of triode detector, shown in Figure 4-20, is in direct contrast to the gridleak type in several ways. It is less sensitive (though far more sensitive than the diode), less easily overloaded, and under proper conditions introduces less distortion. It operates with a fixed bias of such a value that the plate current is about ⅕ of 1 ma (1/5000 amp) until a signal arrives. Thus when a radio signal is fed to the grid, the negative grid-swings have no effect as the plate current is already cut off. This produces the rectifier action. On the other hand the positive swings, though not large enough to make the grid

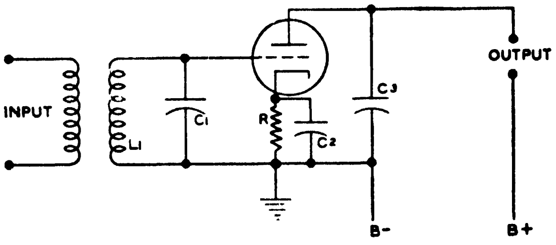


FIG. 4-20. The biased-triode detector.

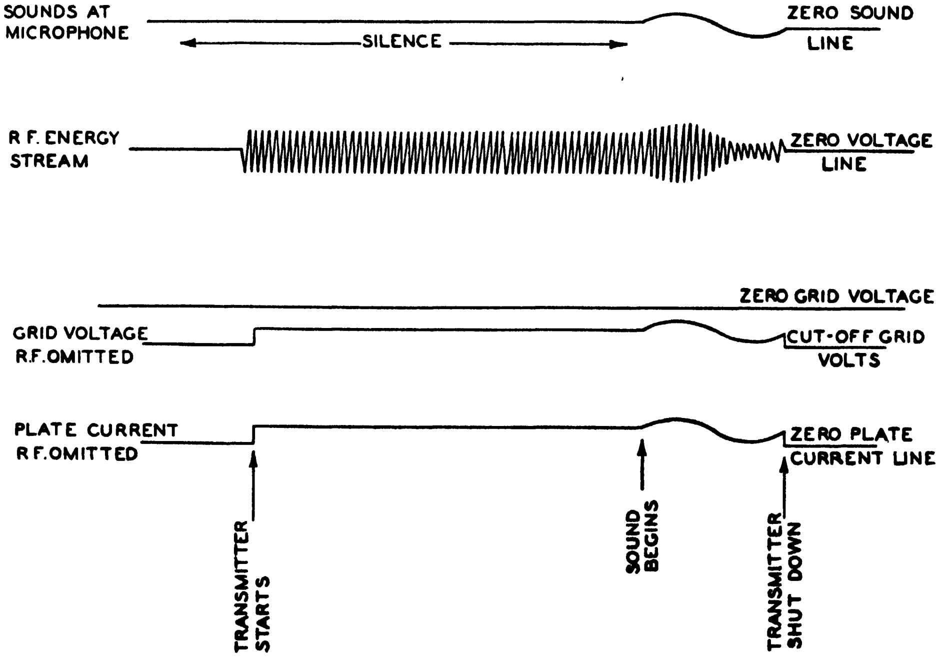


FIG. 4-21. Bias detector action.

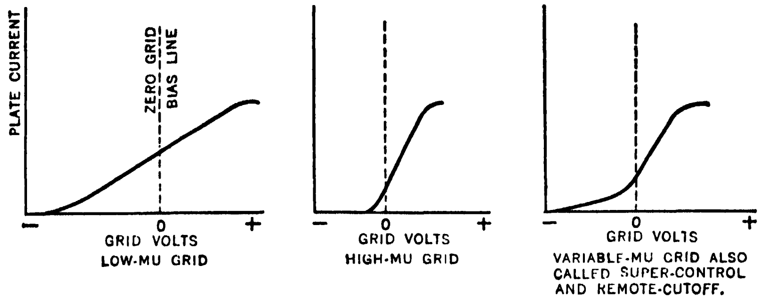


FIG. 4–22. Comparison of grids.

go positive, do swing it in that direction and each alternation lets through a pulse of plate current; hence the average plate current rises in approximate proportion to the strength of the incoming signal and follows any variations therein.

4–13. Cutoff Bias and Variable Mu—Cutoff bias is simply the grid voltage required to block the flow of plate current. If we have a tube working with a plate voltage of 1000 and having a coarse grid so that the amplification constant is only 5, the cutoff bias is ordinarily taken as being 1000/5 = 200, though as a strict fact this voltage does not completely stop the electrons because of changes in their paths. If the tube had a fine grid, placed close to the cathode, and giving a mu of 25, the cutoff bias would be 1000/25 = 40 volts. Thus the high-mu tube is more easily biased and more easily swung by the a-c grid input. The high-mu tube is of advantage in amplifying very small voltages such as weak radio signals or the small voltages from a high-quality microphone but it is also easily overswung by larger voltages. In radio receivers the received signals are of widely differing strengths and the first few stages of a receiver must be able to tolerate strong signals (which suggests low-mu tubes) without being insensitive to weak signals (which require high-mu tubes). A combined type of tube called *variable mu* or *super control* was devised by H. A. Snow and Stuart Ballantine. These tubes are constructed with a grid of which one part is coarse and the other fine (or with different spacing from the cathode) so that one part of the tube is sensitive while the other is proof against blocking by strong signals. The combination works as shown in Figure 4–22. Such tubes are necessary only in the first few stages; after that the automatic volume control has had opportunity to act and the later tubes receive a fairly constant signal level. Variable mu tubes are well suited to automatic volume control because of the difficulty of blocking them with high bias, as explained in the following paragraph.

4–14. Automatic Volume Control—It has already been pointed out that both the diode detector and the biased triode detector produce not only audio

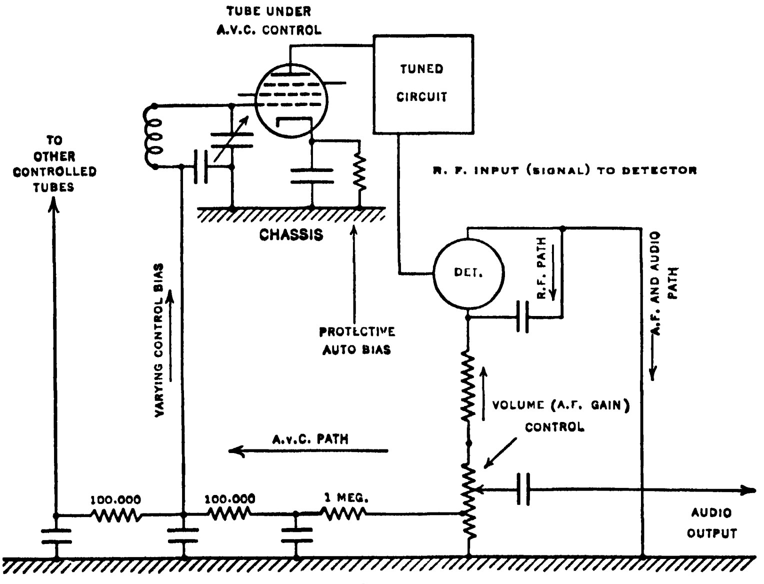


FIG. 4–23. Principle of A.V.C.

output but also a d-c output proportional to this rectified carrrier. Since the d-c component varies with the strength of the incoming carrier, it may be used, after suitable filtering, as an added bias on the first tubes of the receiver. It will then have the very beneficial effect that, as the signal becomes stronger, the d-c detector output also increases, thus increasing the bias voltage on the first tubes, reducing their sensitivity and preventing any large increase in loud-speaker level. This is known as *automatic volume control*, or more commonly AVC. A more exact name is automatic gain control or AGC, but this term is not in common use.

The methods of applying AVC are numerous but all, in effect, consist of passing the detector output through a load resistor, as in Figure 4–23, and at a suitable point tapping it for audio output, while at a lower point tapping it for the AVC voltage which is filtered and thence is applied through branch circuits to the grids to be controlled. The exact circuit depends on a variety of factors, but is illustrated by the circuit of any modern receiver. The tubes thus controlled should be of the variable-mu type to avoid blocking. A good AVC system results in almost uniform output with signal changes of greater than 1000 to 1. To avoid loud background noises due to the great sensitivity when signals fade far down or when no station is tuned in, the AVC circuit is often supplemented by another circuit which blocks the output of the receiver whenever the signals become too weak. The combination is called quiet AVC or QAVC.

4–15. Classes of Amplifiers—*Quick rules for recognizing Classes A, AB, B, and C.* Amplifiers are commonly divided into classes whose engineering definitions appear in the discussions of the following chapter, but which are more easily understood when defined by their more obvious actions and their appearance.

It is first necessary to distinguish between:

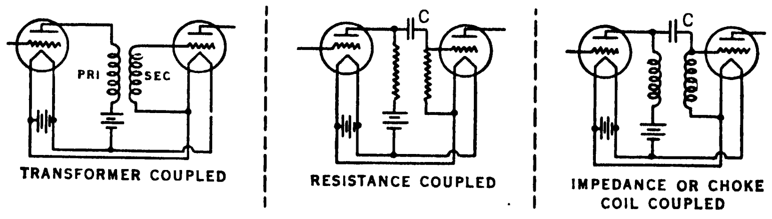
Single-sided amplifier stages
Push-pull amplifier stages
Push-push amplifier stages

A single-tube amplifier is the simplest form of the single-sided amplifier. If more power output is required, another tube may be connected in parallel with the first, that is plate-to-plate, grid-to-grid and cathode-to-cathode, thus in effect making a tube of double size. For audio work this is satisfactory if small resistors are placed in the plate leads to prevent parasitic oscillations. At radio frequencies this tendency is increased and the need of matching tubes increases. Such stages (single or parallel) may employ only Class A for audio operation, but any class for r-f operation.

Another way of connecting more than one tube is the push-pull arrangement in which two tubes are connected as in Figure 4–25. The cathodes are tied together, but the plates and grids are at opposite a-c voltage though at the same d-c voltage. Such an amplifier stage produces approximately double the power of a single tube, and has the very great merit that the a-c output of the stage has small tendency to flow into the plate supply system and thence to other amplifier stages. Furthermore, any even-harmonic distortion appearing in this stage is largely cancelled in the output transformer. Push-pull stages may be of class A, AB, or B in audio work and of any class in r-f work.

Still another connection is the push-push stage which is connected as in Figure 4–26. Here it is seen that the grids are connected as in a push-pull stage but the plates are in parallel. Such a stage doubles the input frequency and is used for that purpose in transmitters.

In audio work we are always concerned about distortion, while in r-f amplification we can and do



TRANSFORMER COUPLED

RESISTANCE COUPLED

IMPEDANCE OR CHOKE COIL COUPLED

FIG. 4–24. Methods used to couple vacuum tubes in an amplifier.

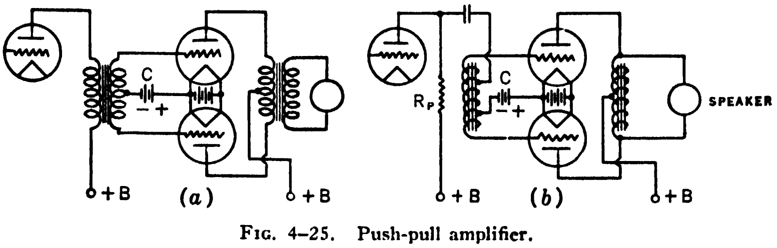


FIG. 4–25. Push-pull amplifier.

tolerate distortion in the tube for the reason that the additional frequencies created by the distortion are readily removed by the tuned circuit in the tube's plate circuit. Hence, in general, an audio amplifier must be a better amplifier than the r-f amplifier, and not all classes of amplification will pass the requirements.

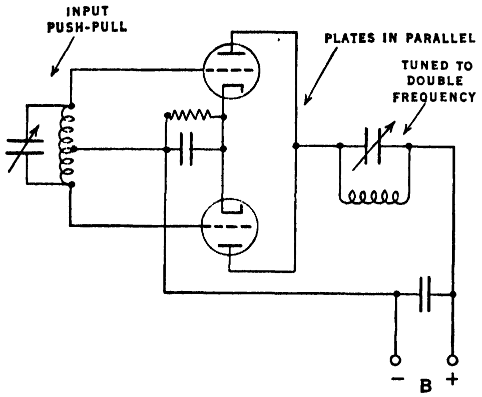


FIG. 4-26. Push-push frequency doubler.

A *Class A amplifier* may use one or two tubes in either a single-sided arrangement or in push-pull and may employ a variety of interstage couplings, that is, the devices which couple the output of one stage to the following stage. The one sure indication of this type of operation is that a meter placed in the d-c plate supply lead shows little or no movement even in going from minimum to full volume. This steady plate current heats the tubes to no useful purpose, and the efficiency at full output seldom exceeds 20 percent.

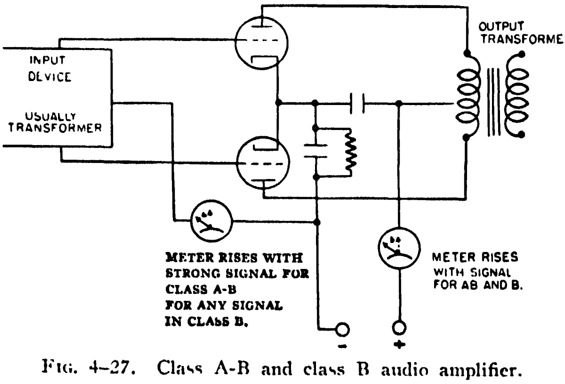

OUTPUT TRANSFORMER
INPUT DEVICE
USUALLY TRANSFORMER
METER RISES WITH STRONG SIGNAL FOR CLASS A-B FOR ANY SIGNAL IN CLASS B.
METER RISES WITH SIGNAL FOR AB AND B.
−
+

FIG. 4-27. Class A-B and class B audio amplifier.

A *Class AB amplifier* differs from the foregoing in degree rather than by sharp division. The plate current varies with signal level, but the extent of the variation differs quite widely with the tube type. The bias used is larger and the static plate current smaller than for Class A operation of the same tubes. Hence, the heating is less, efficiency greater and output 150 to 200 percent that of Class A. The stage is always push-pull connected for audio and seldom used for r.f. The fidelity, with proper design, is not materially below Class A. In the lower part of the range no grid current appears. This is the AB1 region. For larger signal swings (AB2) small grid currents appear and actual power must be supplied by the driving stage which accordingly feeds the class AB stage through a transformer without step-up and usually with a step-down—that is, with secondary turns equal to or fewer than the primary.

A *Class B stage* is difficult to distinguish from the AB type since the plate current swings may be either less than or more than those of Class AB2, depending upon the type of tubes used. Class B operation is clearly intended if the tube tables and the voltmeter show that the bias used is near the cutoff value. Likewise Class B operation is intended if the tubes are of a very-high-mu type, operating with no bias whatever. Ordinary meters do not permit noting the real difference between this type of operation and the preceding classes, namely, that the Class B tube works on only ½ of each grid cycle, so that the output of one Class B tube is an amplified and rectified copy of the input. For r-f amplification this does not matter as the tuned plate circuit acts as a pendulum and supplies the missing half cycle, but for audio it is necessary to use two Class B tubes operating in push-pull, each tube supplying alternate half-cycles. They must be *much* better matched than in either Classes A or AB in order to give good fidelity. A Class B audio push-pull amplifier will deliver about 5 times the output of the same tubes in Class A, or 2½ times the Class AB output.

The *Class C stage* is used in r-f work only and differs from the preceding classes in the use of an extremely high grid bias, equal to at least *twice* the cutoff value, and furthermore in the use of a *steady grid input* or excitation, also very high. Offhand, this appears to leave no possibility of anything but a steady r-f output; in fact, Class C stages are used in exactly that manner for telegraphy, by merely cutting off the grid input when the key is up, the high bias stopping all tube action.

4-16. Modulation—Class C amplifier stages have another use. With the input to the grid both fixed and high, it is obviously possible to vary the output by changing the d-c voltage of either the grid or plate. This can be done by connecting the output of an audio amplifier to a transformer whose secondary winding is connected in such a d-c supply lead. The d.c. passing through the transformer secondary will have the audio voltage alternately added to and subtracted from it, varying the voltage applied to the tube element and hence the tube output (Figure 4-28). This operation of modulation can be applied not only to the grid or plate of a triode, but also to the screen, suppressor and other element of the more complex tubes. Plate modulation requires the greatest audio power, but it also

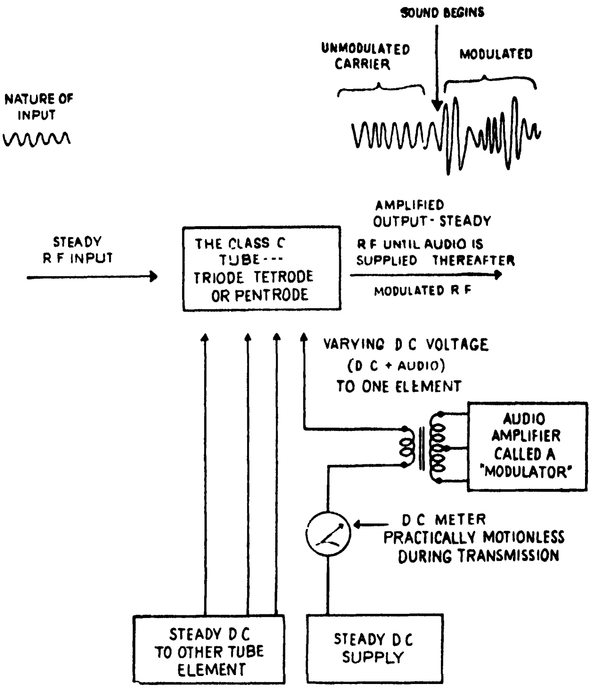

SOUND BEGINS
UNMODULATED CARRIER
MODULATED
NATURE OF INPUT
AMPLIFIED OUTPUT - STEADY R F UNTIL AUDIO IS SUPPLIED THEREAFTER
MODULATED R F
STEADY R F INPUT
THE CLASS C TUBE --- TRIODE TETRODE OR PENTRODE
VARYING D C VOLTAGE (D C + AUDIO) TO ONE ELEMENT
AUDIO AMPLIFIER CALLED A "MODULATOR"
D C METER PRACTICALLY MOTIONLESS DURING TRANSMISSION
STEADY D C TO OTHER TUBE ELEMENT
STEADY D C SUPPLY

FIG. 4–28. The principle of modulation by variation of the voltage of a tube element. Depending on the element the result is plate modulation, plate-screen modulation, screen modulation, control grid modulation or suppressor grid modulation. The output waveform is of the same nature for all methods.

produces the most output from the transmitter. Suppressor-grid modulation and control-grid modulation are at the other end of the list in both regards.

4–17. Regeneration and Degeneration—Since the output of an amplifier stage is greater than the input, it is possible to return a portion of the output to the grid for further amplification, thereby increasing the gain provided by the stage. The return of output voltage to the control grid is called *feedback* or *regeneration*. Since it is possible to reverse the direction of the feedback voltage, we may also use this device to oppose the grid voltage and thus reduce the stage gain, which process is called *reversed feedback* or *degeneration*.

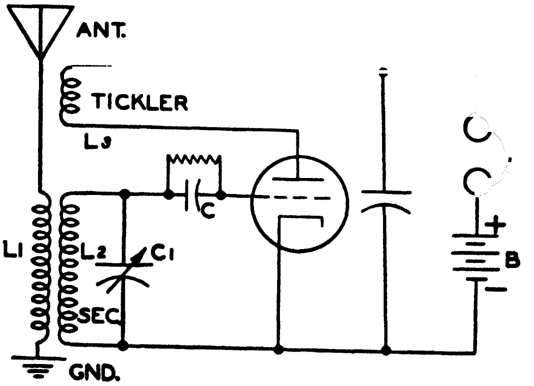


FIG. 4–29. Regenerative detector circuit.

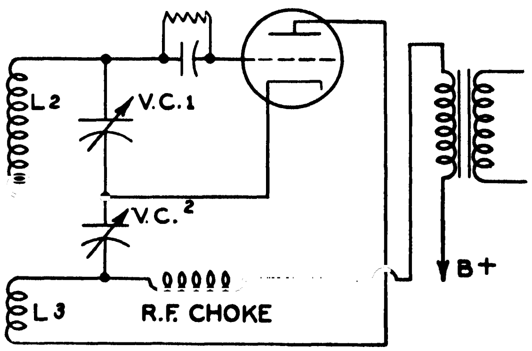


FIG. 4–30. ' Capacitive control of regeneration.

4–17a. The Regenerative Detector—It will be recalled that in the detector discussions of section 4–12 the amplified r.f. appearing in the plate circuit was intentionally discarded by returning it to the cathode. Where unusual detector sensitivity is essential, as for example in the case of a simple one- or two-tube receiver, this r.f. in the plate circuit may be utilized to produce regeneration by means of circuits such as shown in Figures 4–29 and 4–30. Coil L_3 in the plate circuit, known as the tickler, carries the complete plate current, that is, d.c., r.f.

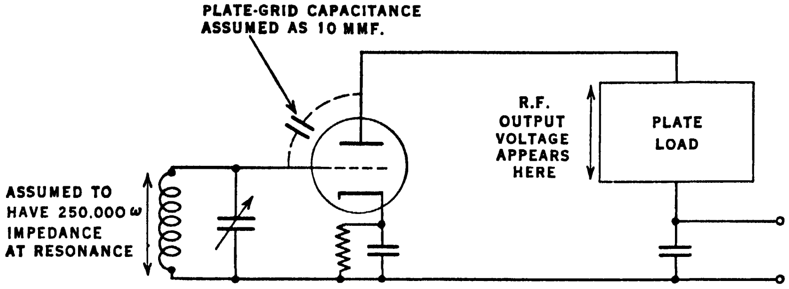


FIG. 4–31. Exaggerated case of feedback.

and audio, but has only a few turns so that its audio and d-c effect is negligible. It is, however, large enough to act as the primary of a radio-frequency transformer when brought near coil L_2, which acts as the transformer secondary and returns a portion of the plate power to the grid. Control of the regeneration is accomplished by moving L_3 in relation to L_2 or by varying the condenser in the plate circuit so as to change the impedance which it offers to the r.f., thus controlling the r-f current in the plate circuit.

The regenerative detector may be easily made 50 to 100 times as sensitive as the nonregenerative detector, but it is correspondingly easily overloaded and critical in operation.

4–17b. Regeneration by Plate Loading—An altogether different way of producing regeneration is possible and is unintentionally the cause of most circuit instability in both receivers and transmitters. If any amplifier tube is given a plate load of high impedance at the operating frequency, then the tube is able to create a considerable voltage across this load. Looking at Figure 4–31 it can be seen that there are connected across this load voltage the grid-input circuit in series with the small interelectrode capacitance of the grid and the plate. The action can be illustrated by an intentionally exaggerated case. Let us suppose that the operating frequency is 1,000,000 cycles per second, that the tuned grid circuit has an impedance of 250,000 ohms at this frequency, and that the plate-to-grid capacitance is 10 $\mu\mu$f which, at 1,000,000 cycles, presents a reactance of about 16,000 ohms. The r-f voltage in the plate circuit feeds back through the plate-grid reactance of 16,000 ohms and the portion appearing across the tuned grid circuit is evidently:

$$\frac{250{,}000}{250{,}000 + 16{,}000} = 94\%$$

As stated, this is an exaggerated case to stress the point that feedback through the plate-to-grid takes place *whenever the plate load is high enough.* Unfortunately this is just the condition under which the highest amplification is secured in a tuned r-f amplifier, so that high gain and a tendency toward regenerative instability are always found together, the effect increasing with frequency because the reactance of the plate-to-grid capacity is falling, and making feedback easier.

Moreover, no plate load remains constant at all frequencies, hence irregular variations of regeneration are the rule.

4–17c. Effect of Phase-shift on Regeneration—It has already been stated that if the feedback voltage is reversed the effect is degenerative rather than regenerative. A departure from in-phase (additive) feedback is therefore a departure from the strongest regeneration so that feedback due to the plate load depends not only on the size of the plate load, but also on the nature of its reactance. This is readily illustrated by the Armstrong circuit of Figure 4–32. Here the plate load is a pure (and very high) resistance when the plate circuit is tuned to exact resonance, and may be made either capacitive or inductive by detuning to one side of resonance or the other. The result will be found to be a wide variation in efficiency.

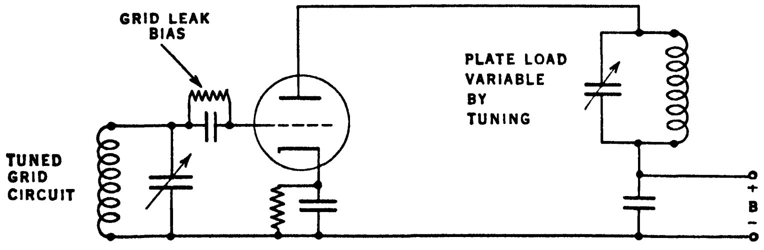


FIG. 4–32. Armstrong circuit. By tuning plate circuit near resonance large regenerative amplifier gain or steady oscillation may be produced at will.

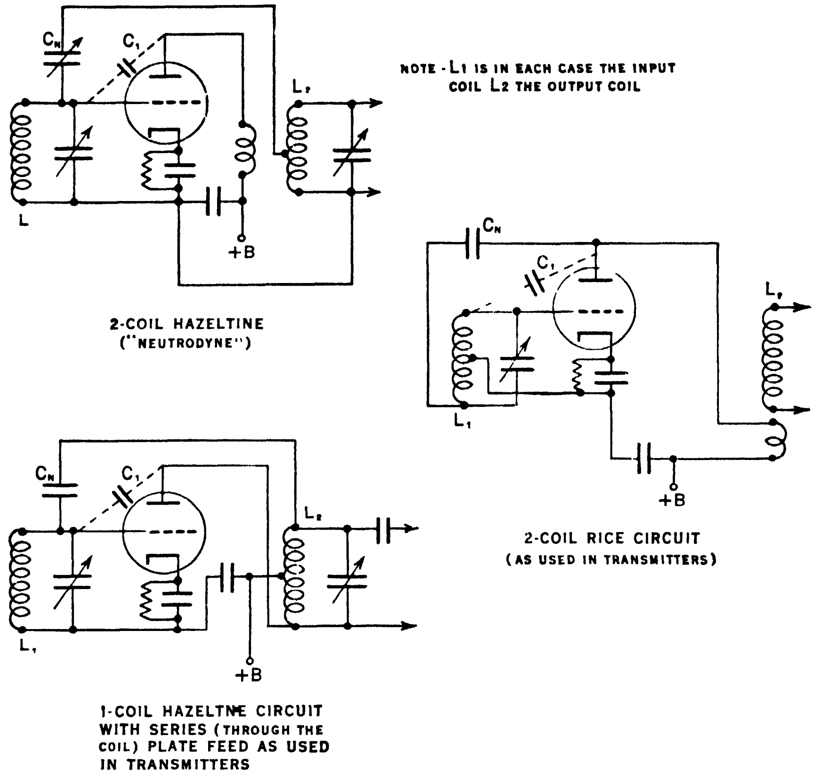

CN
C1
L2
L
+B
NOTE - L1 IS IN EACH CASE THE INPUT COIL L2 THE OUTPUT COIL
2-COIL HAZELTINE ("NEUTRODYNE")
CN
C1
L2
L1
+B
2-COIL RICE CIRCUIT (AS USED IN TRANSMITTERS)
CN
C1
L2
L1
+B
1-COIL HAZELTNE CIRCUIT WITH SERIES (THROUGH THE COIL) PLATE FEED AS USED IN TRANSMITTERS

Fig. 4–33. Neutralizing circuits used in r.f. transmitting amplifiers.

4–17d. Regeneration in Transmitters—In the r-f amplifier chain of a transmitter most of the tubes have plate loads consisting of tuned circuits set for the maximum output, which is also the favorable condition for maximum regeneration and instability. In most of the stages this regeneration is not wanted, hence transmitters commonly have antiregenerative devices applied to most of their r-f stages.

4–17e. Antiregenerative Devices for r-f Amplifiers—Antiregeneration systems depend on providing an additional feedback path external to the tube but of reverse nature, so that the regenerative feedback through the tube shall be met at the grid by an equal and opposite degenerative feedback. To accomplish this there have been devised a number of neutralizing or balancing circuits, differing in their complexity, ease of adjustment and ability to stay in balance with changes of frequency or temperature. A number of these circuits have the common nature of becoming less balanced when the operating frequency is changed, as in tuning a receiver—either because the circuit is inherently incapable of remaining balanced except at one frequency or because it is not possible in practice to attain theoretically ideal conditions. Depending on the circuit and the adjustment, it is possible to cause regeneration to rise with rising frequency or to fall with rising frequency, the latter being preferable as it compensates for the slope of the gain curve due to a changing L/C ratio—that is, the tendency of an r-f tuned amplifier to amplify less at that end of the range where more capacitance (but the same coil) is operative.

4–17f. Neutralization Circuits Used in Transmitter R-f Amplifiers—Figure 4–33 shows the Rice neutralization circuit. Coil L_1 receives r-f energy from an outside source at the frequency to which it is tuned by the condenser across its terminals. The upper half of the coil feeds the r-f voltage to the grid and amplification proceeds in the usual manner, producing an amplified r-f voltage across the output coil. A portion of this voltage now returns to the grid through the plate-grid capacitance, which has been shown as condenser C_1. If that were all, the stage would be highly regenerative and unstable. However, at the same time some of the voltage from the upper end of the output coil is being returned through the neutralizing condenser C_n to the end of L_1 which is *opposite* the grid, thus opposing the voltage which returned to the grid via C_1. A simple way of explaining the opposition and cancellation between the feedback voltage via C_1 and that via C_n is that the tuned coil L_1 acts as an electrical see-saw, pivoted on its center-tap. Like any see-saw it tends to come to rest if both ends are pushed down at the same time. Thus the undesired grid voltage is cancelled and only that arriving from the preceding stage (not shown) excites the grid.

Figure 4–33 also shows the Hazeltine neutralizing circuits. The latter are in effect the Rice circuit transported to the plate side of the tube. From one end of the plate load an r-f voltage returns through C_1, while from the other end of the plate load an opposing voltage returns to the same grid, cancelling the original feedback.

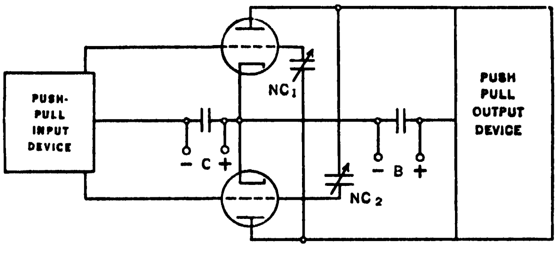


FIG. 4–34. Ballantine cross-neutralization of a push-pull stage. (The grids are normal, being shown double-ended solely to simplify the diagram.)

Figure 4–34 shows the Ballantine method of cross-neutralizing a push-pull r-f amplifier stage. Study of this circuit will show that if one of the neutralizing condensers is removed both tubes will still be capable of neutralization by readjusting the remaining neutralizing condenser. In this condition one of the tubes is Rice-neutralized and the other is Hazeltine-neutralized, but the adjustment is rather delicate and tends to go out of balance with changes of voltage such as occur during modulation, or with small changes of tuning. The complete Ballantine circuit is superior in these regards. For tubes which are fairly well matched it is possible to couple the two neutralizing condensers mechanically (but not electrically) so as to give single control neutralization.

4–17g. Regenerative Oscillators—From what has been said in foregoing sections it can be seen that the normal tendency of a triode amplifier is to regenerate when provided with a load of adequate size and of such nature as to permit high amplification. If no brake is applied, the regeneration tends to feed back enough voltage so that the grid swings rise rapidly in amplitude, with a consequent rise in the a-c plate voltage until the swings are as great as permitted by the plate supply voltage and cathode emission. The tube is now *oscillating*.

Figure 4–35 shows various circuits capable of providing dependable regenerative oscillation. Other oscillators using triodes, tetrodes and pentodes are shown in Figure 4–37. They all depend on one of two basic ideas, already covered in previous discussion:

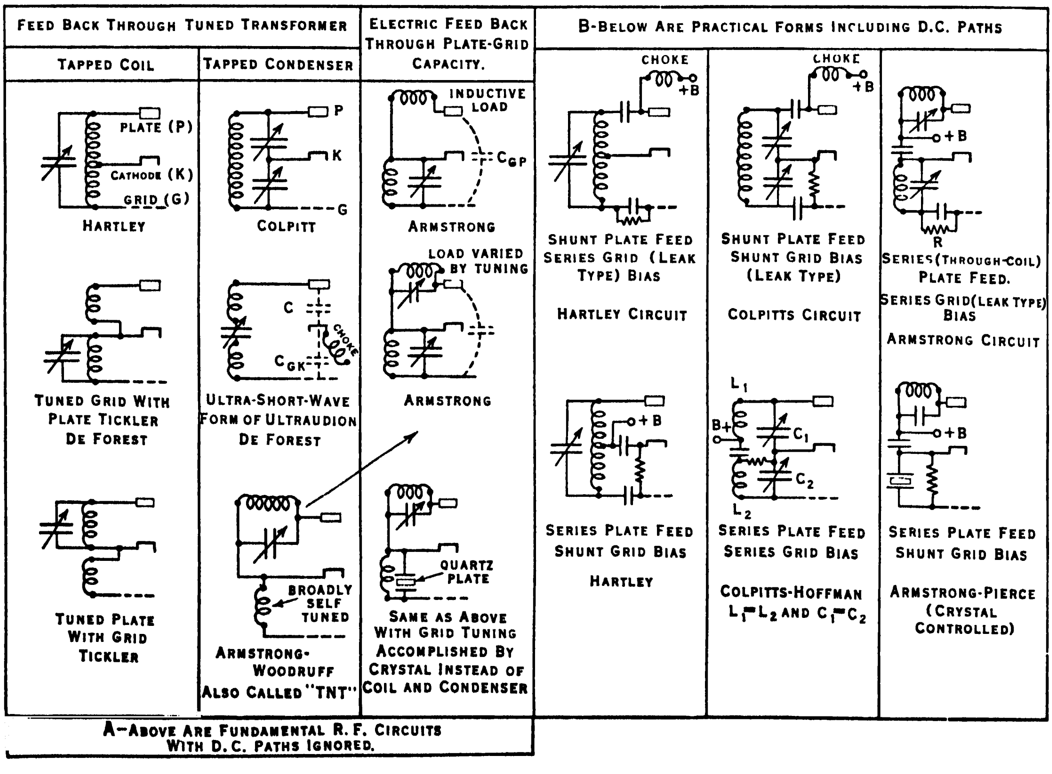

FEED BACK THROUGH TUNED TRANSFORMER
TAPPED COIL
TAPPED CONDENSER
ELECTRIC FEED BACK THROUGH PLATE-GRID CAPACITY.
B-BELOW ARE PRACTICAL FORMS INCLUDING D.C. PATHS
PLATE (P)
CATHODE (K)
GRID (G)
HARTLEY
P
K
G
COLPITT
INDUCTIVE LOAD
CGP
ARMSTRONG
LOAD VARIED BY TUNING
ARMSTRONG
TUNED GRID WITH PLATE TICKLER DE FOREST
C
CHOKE
CGK
L
ULTRA-SHORT-WAVE FORM OF ULTRAUDION DE FOREST
TUNED PLATE WITH GRID TICKLER
BROADLY SELF TUNED
ARMSTRONG-WOODRUFF ALSO CALLED "TNT"
QUARTZ PLATE
SAME AS ABOVE WITH GRID TUNING ACCOMPLISHED BY CRYSTAL INSTEAD OF COIL AND CONDENSER
CHOKE
+B
SHUNT PLATE FEED SERIES GRID (LEAK TYPE) BIAS
HARTLEY CIRCUIT
CHOKE
+B
SHUNT PLATE FEED SHUNT GRID BIAS (LEAK TYPE)
COLPITTS CIRCUIT
+B
R
SERIES (THROUGH-COIL) PLATE FEED.
SERIES GRID (LEAK TYPE) BIAS
ARMSTRONG CIRCUIT
+B
SERIES PLATE FEED SHUNT GRID BIAS
HARTLEY
L1
B+
C1
C2
L2
SERIES PLATE FEED SERIES GRID BIAS
COLPITTS-HOFFMAN L1=L2 AND C1=C2
+B
SERIES PLATE FEED SHUNT GRID BIAS
ARMSTRONG-PIERCE (CRYSTAL CONTROLLED)
A—ABOVE ARE FUNDAMENTAL R. F. CIRCUITS WITH D. C. PATHS IGNORED.

FIG. 4–35. Regenerative triode oscillators.

(*a*) A tuned circuit is provided with the grid and plate connected to opposite ends thereof so as to maintain them at opposite a-c voltages, while the tube swings or oscillates. The feedback is via the tuned circuit.

(*b*) A tuned circuit is placed in one branch (grid or plate) and the other branch is provided with either a high impedance or another tuned circuit adjustable as to resonance-frequency so that it may be made to have a high inductive reactance. The feedback is via the tube's plate-grid interelectrode capacitance.

(*c*) A tuned circuit is place in one branch but the other branch is coupled to it magnetically to give action equivalent to (*a*) above.

(*d*) A tuned circuit is replaced by a quartz crystal plate.

In modern transmitters these oscillators are employed mainly as drivers of a multitube amplifier system and are not called upon to generate much power. This permits the use of a small tube, protected from temperature changes by a suitable enclosure. and from voltage changes by a small independent power supply. It is thus possible to provide exceptional frequency stability, keeping the station well within the authorized frequency tolerance. Crystal-controlled oscillators offer especial advantages in this regard. Attention is called to the more complete oscillator discussion in the following chapter.

4–18. Frequency and Power Limits of Vacuum Triodes—In most tube applications the limit as to power output is set by heating of the tube, though it is also possible to encounter difficulty with the tube's insulation or to injure the filament while heating does not appear excessive. These latter difficulties are usually met when operating the tube with small plate current, high plate voltage and grid bias, and very strong grid excitation. Under these conditions the plate current consists of very brief pulses, much less than ½ cycle in duration, but of very great momentary amplitude. These pulses are quite capable of damaging the filament and quickly reducing its emission. Caution is therefore necessary when attempting to operate triodes in the manner indicated, whether for the purpose of frequency-multiplying or for the purpose of obtaining high r-f output.

As the frequency is increased there arrives a point at which the tube must be operated at lower plate voltage to avoid gradual or immediate damage. This is due to the fact that the tube does have internal capacitances and that, as the frequency rises, more and more r-f current is sure to flow through any condenser, tending to heat it. Thus as the frequency is increased, a larger and larger share of the r-f current flows through the tube capacitances until a number of amperes may be flowing through the grid, though its d-c grid current indicates only a fraction of one ampere. As the permissible heat-dissipation in the grid is limited, the voltage must be lowered, with lesser output as a consequence.

Another effect enters here. Not only does the feedback current flow through the vacuous space, it also flows through any insulation material lying between the tube elements—even via portions of the glass envelope or the tube base. Older tubes were frequently destroyed by the resultant local heating when used at higher frequencies, but modern tubes are designed to avoid such losses. Finally there is a frequency limitation due to the length of the wires passing from the tube elements to the outside of the tube.

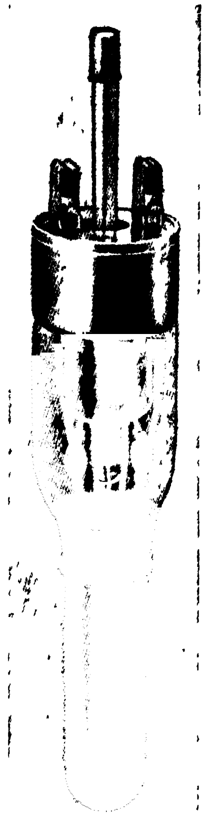


FIG. 4–36. Western Electric 5-kw. water cooled power tube.

4–19. Water-cooled Tubes—Water-cooled tubes do not differ as much from air-cooled tubes as their appearance, Figure 4–36 suggests. One end of the tubular plate has been closed by a metal head, and the opposite end by a glass seal through which the grid and cathode leads enter, the actual cathode and grid occupying the usual positions within the plate. As opposed to a complete glass enclosure, this construction has the advantage that the plate is exposed and can be cooled by water flowing around it through a metallic water-jacket, in which the tube rests on a flange provided for that purpose and made tight by a rubber gasket. The more rapid removal of heat by the water makes possible much larger outputs from the same size tube (though the filament must be larger) and also makes possible vacuum tubes of much higher power capability.

Water-cooled tubes are at a disadvantage at very high frequencies, partially because of the mass of metal which forms the water-jacket. Modern types perform, however, quite satisfactorily at high frequencies.

Water-cooled tubes are in many cases provided with air-blast cooling of the glass portions, and there have been designs in which water flows into hollow grid and plate structures to cool them. Such devices are due to the necessity of disposing of the heat liberated by the filaments, which amounts to many kilowatts in the larger tubes.

4–20. Safe Dissipation Limits—Plate dissipation is that power which is left on the plate as heat, and must be removed by the cooling water or, in the case of an air-cooled tube, must be removed by radiation through the glass envelope, possibly with the aid of an air blast directed on the glass to remove that share of the heat which fails to penetrate the glass in radiant form. The power fed into the plate is:

Watts input = Plate supply voltage × plate input amperes

Neither the voltage nor the current should exceed the manufacturer's rating for the type of service intended. The widespread impression that it is good economy to overrun tubes is true only if one is making a definitely temporary use of the equipment; it cannot be substantiated for long-term operation.

Plate circuit efficiency or conversion efficiency is the portion of the input power which emerges as output. It is usually stated in percent efficiency.

This leaves the portion of the input which has not been converted into output and which stays in the tube as heat constituting the main limitation of tube operation. *If this dissipation cannot be kept below the limit recommended by the manufacturer, the input must be reduced if normal tube life is to be obtained.*

Excessive heating may result in damage to the tube, either by the release of gas and destruction of the vacuum or by reducing the insulation of the tube and leading to early failure by internal short circuit, or by cracking of a seal and the admission of air with the consequent oxidation of the filament—giving the familiar milky white smoke and burnout. Indirect damage may be done to the filament without actual cracking and leaking.

Excessive heating of other elements is also quite possible; hence both the d-c and the r-f currents to all grids must be kept within recommended limits. Graphite plates do not show color until the losses far exceed safe limits. Even a few minutes of dull-red operation may greatly shorten the tube life.

4–21. Reactivation of Damaged Filaments—The oxide-coated type of filament, once damaged, is incapable of repair unless the tube is sent to a repair shop, opened and reworked. The active coating has been removed from the surface of the filament.

However the thoriated type of filament may have suffered no damage except to have the thorium stripped from the surface layer at a rate too great to permit replacement by diffusion from inside the filament. In this case reactivation may be attempted as follows:

(*a*) Remove voltages from all tube elements except the filament.
(*b*) Operate the filament at normal voltage for 20 minutes.

If this does not effect a remedy, flashing and seasoning may be tried:

(*c*) Operate the filament at 300 percent normal voltage for 30 to 60 seconds. This is flashing.
(*d*) Season at 150 percent normal voltage for 10 minutes.
(*e*) Restore to normal operation. If emission is still low—discard. Some burnouts will take place during treatment.

Oxide-coated or indirectly heated cathodes are severely damaged by this treatment—be sure of the type. Pure tungsten cathodes will *certainly* be burned out and cannot possibly be benefitted by treatment. If it fails to produce emission at normal voltage, the tube is defective and must be repaired or discarded.

4–22. Composite Vacuum Tubes—A virtually endless variety of tubes is possible by combining several tubes in one envelope. In most cases this provides mere mechanical compactness and provides nothing which could not be accomplished by employing conventional diodes, triodes, tetrodes, and pentodes. In this classification are such tubes as:

(*a*) Plate-supply rectifier and audio power tube in one envelope.
(*b*) Detector diode in same envelope with amplifier triode, tetrode, or pentode.
(*c*) The same with a double diode.
(*d*) Two identical triodes in same envelope.
(*e*) Two triodes of different type in same envelope permanently connected as voltage driver and power stage.

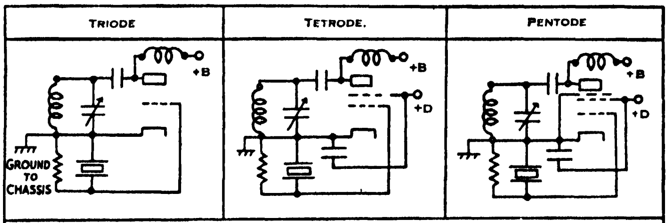
There are some tube types which accomplish results not equally well attained by independent tubes. A notable example of this is the penagrid converter outlined in the following section.

4–23. The Dow Electron-coupled Oscillator—Consider a triode whose plate is made of a wire mesh. Some electrons will penetrate this mesh and if the triode is made to oscillate it is clear that the electron stream coming through the mesh will be pulsating. This pulsating electron stream may be attracted by a second plate placed beyond the mesh plate. This second plate is maintained at a higher voltage than the first and receives a pulsating electron stream which emerges from the second plate as a pulsating plate current, the pulsations, of course, being at the frequency at which the triode is oscillating. The combination of a triode with a mesh plate, backed by another plate, is nothing but an ordinary tetrode, the mesh plate being the screen. The circuit can be modified in many ways without losing the fundamental advantage that the output element is coupled to the oscillator only by electron coupling, hence the oscillator is relatively well protected from outside influences such as changes of load. Figure 4–37 shows some circuit forms, all rather manifest descendants of the oscillators of Figure 4–35, with the ground moved to the screen to give the best protection against unwanted screen-to-plate coupling other than the desired electron coupling.

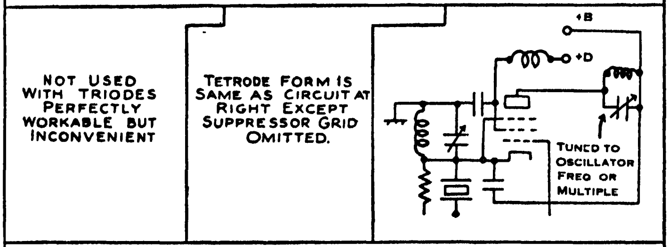
Dow electron-coupled oscillators, like others, produce a highly distorted wave form when oscillating strongly; hence numerous harmonic frequencies (multiples of the original frequency) are present and can be derived by merely equipping the plate circuit with a circuit tuned to the desired harmonic. Further strengthening of the harmonic is possible by the means suggested in Figure 4–37c). The coil L_2 is tuned so as to present reactance at the grid-circuit frequency (not to resonance), while the coil L_3 is tuned for maximum output at the desired harmonic frequency.

The Dow oscillator has at times been explained as consisting of a triode oscillator plus a tetrode amplifier and some forms have been given names such as "tri-tet" intended to describe this concept.

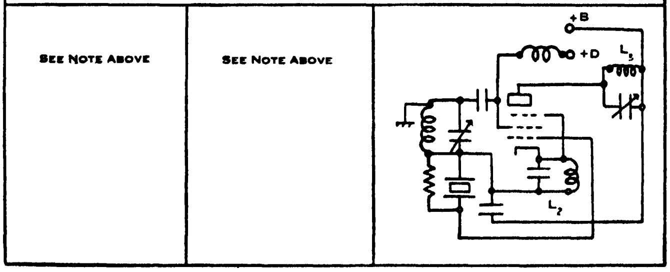
4–24. Other Oscillators: Barkhausen-Kurtz, Magnetron—The oscillators thus far described depend upon regeneration, that is, they are amplifiers in which a portion of the output is returned to the grid. In addition we have another class of oscillators using vacuum tubes. These are the types



A- SIMPLE CRYSTAL-CONTROLLED OSCILLATORS ARMSTRONG-PIERCE TYPE.


NOT USED WITH TRIODES PERFECTLY WORKABLE BUT INCONVENIENT
TETRODE FORM IS SAME AS CIRCUIT AT RIGHT EXCEPT SUPPRESSOR GRID OMITTED.
+B
+D
TUNED TO OSCILLATOR FREQ OR MULTIPLE

B- CRYSTAL CONTROLLED OSCILLATORS OF THE "ELECTRON COUPLED" TYPE IN WHICH SCREEN REPLACES PLATE AND LATTER SERVES ONLY AS AN OUTPUT ELECTRODE ARMSTRONG-PIERCE-DOW TYPE



C- LAMB FORM OF ARMSTRONG PIERCE-DOW OSCILLATOR.

FIG. 4–37. Crystal controlled oscillator circuits.

in which we do not merely vary the size of the electron stream as it passes from cathode to anode, but rather stop the electron in its progress toward the anode and cause it to zig-zag in the vacuous space. These zig-zags may be made very short, hence the frequency of oscillation may be made very high.

One form of such oscillation is that of the Barkhausen-Kurtz oscillator of Figure 4–38. This is a triode oscillator but the grid is positive and eventually captures all the emitted electrons, which is normally a plate function. Therefore, the grid current is large, the grid heats strongly, and the tube must be operated at very low power. The plate is negative and serves to drive back the electrons which penetrate through the meshes of the grid, whereupon it is presumed that the electrons zig-zag their way back to the grid. The frequency is determined mainly by the tube dimensions and voltages, but is influenced by any circuit connected to the tube and tuned near the oscillation frequency or some multiple of it. With proper tuning this output circuit materially strengthens the effect, but only a few watts at best are obtained at the centimeter waves for which this oscillator is employed.

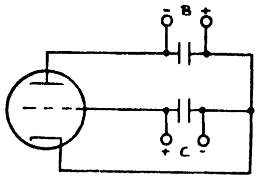


Fig. 4–38. Barkhausen-Kurtz non-regenerative oscillator. (Note polarities of d c. grid and plate supplies.)

Another type of wandering-electron oscillator is that based on the magnetron which in its simplest form is a diode consisting of a straight filament running down the center of a tubular plate, the entire tube being surrounded by a strong magnetic field parallel to the filament—that is, lengthwise of the tube. If the magnetic field is made strong enough, the plate current of such a tube ceases until the plate voltage is raised, whereupon it can again be shut off by increasing the magnetic field. The magnetic field causes the electrons from the filament to spiral instead of going out radially, and with a strong field to flatten out into a circle, like moons revolving around a planet If the plate is split lengthwise and the two halves brought out through

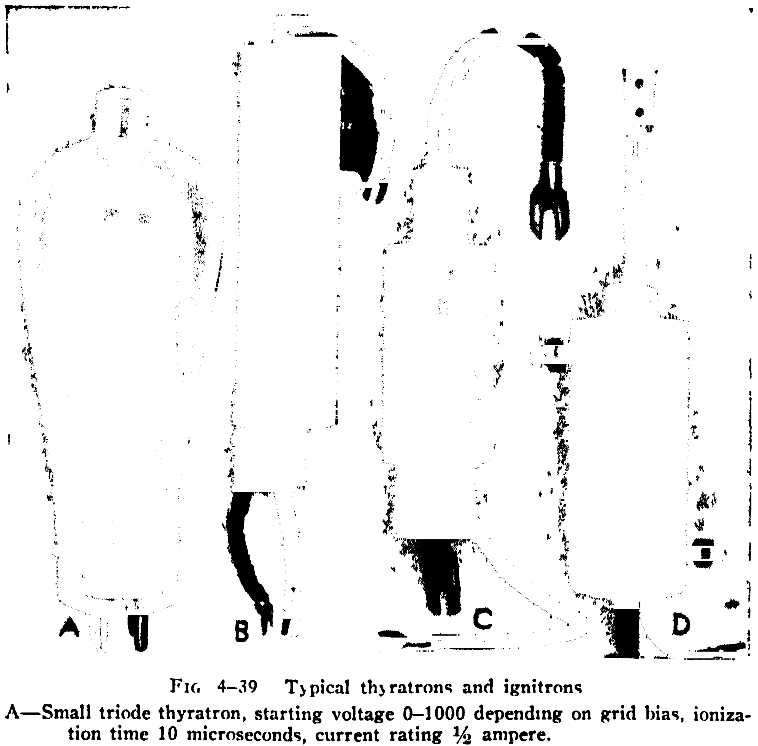


Fig 4–39 Typical thyratrons and ignitrons

A—Small triode thyratron, starting voltage 0–1000 depending on grid bias, ionization time 10 microseconds, current rating ½ ampere.

B—Metal-shell tetrode thyratron, current rating 6.4 amperes, other characteristics as above.

C—Small glass-body ignitron showing construction. Current rating 2.4–4 amps. average, 600 peak Igniter current 15 amps.

D—Metal-shell water-cooled ignitron, current rating 50–100 amperes for short times, 6000 amperes peak under proper conditions Igniter current 40 amperes. (Courtesy General Electric Company.)

separate connections, it is found that a-c voltages can be made to appear between the two plates by correct adjustment of plate voltage, filament temperature, and magnetic field, which factors also determine the frequency.

Another form of magnetron oscillator has the magnetic field at right angles or at an intermediate angle, and produces a somewhat different effect.

4–25. Mercury-vapor Diodes, Triodes, and Tetrodes—A family of nonvacuum tubes giving much more pronounced effects and capable of additional new effects consists of the tubes containing metallic vapors, commonly those of mercury. The mercury ion is important in these tubes because it is a metallic ion, physically and electrically quite enormous as compared to the electron. It is thus possible for a mercury ion to transport electrons in quantity and to accomplish the essential elimination of the obstructing space charge, which reduces the voltage drop through the tube to a fraction of its former value and makes it nearly constant, even though much larger currents are being passed. The 217C vacuum diodes are of the same size as the 872A mercury-vapor diodes, indicating about the same heat-dissipating ability, yet a pair of the former have a maximum rated output under 1 kw while the 872A mercury-vapor tubes deliver 8 kws at materially better efficiency, without requiring materially more filament power to produce the original emission. Mercury-vapor diodes are used principally as power supply rectifiers, and are further discussed under "Power supply rectifiers and filters" in section 4–27 of this chapter.

The mercury-vapor triode is not encountered as commonly in radio work as in power control and distribution devices, where it is extremely active under such names as *thyratron* which is the General Electric trade name but very aptly explains the tube since it means "a gate device." The mercury triode with hot cathode does not pass large forward currents as does the diode—for this time the gate has a latch, called the grid. If the plate voltage is increased the latch will be pushed open unless we cause it to latch more tightly by raising the grid bias at the same time. In either case we have a blocked or cutoff triode until the latch does slip, but from that instant the tube acts quite differently from a high-vacuum triode for the grid loses control completely and the gate swings wide open, letting current flow through with only about a 12 to 14 volt drop as compared to 40 to 10,000 volts in a high-vacuum triode. This current continues to flow until the plate voltage is removed long enough to permit the mercury vapor to de-ionize, the time varying with tube design and temperature. If the plate supply is a.c., the grid can recover control during each negative half-cycle, so that a large alternating current may be interrupted *noiselessly and instantly* by a few volts applied to the grid. Furthermore, the amount of a.c. flowing can be controlled by setting the grid voltage so that only a part of each positive half-cycle passes. If the grid bias is d.c., less than ¼ cycle cannot be passed except by cutting off completely, but with a-c grid voltages it is possible to use phase-shifts so as to pass practically any desired portion. Two thyratrons thus constitute a full-wave switch of remarkable capabilities.

There are also mercury-vapor tetrodes whose abilities may be inferred from previous discussion.

One special vaporous tube, called the *ignitron,* is exceptional as compared to all others. This is a triode but of a very unconventional structure. It consists of an anode suspended over a mercury pool into which dips the third element. This third element fulfills the function of the grid in the thyratrons, but in a wholly different manner. As there is no hot cathode the tube has little initial tendency to conduct, and instead of being in need of restraint by a negative grid it must rather be ignited into action. This is provided by the third or igniter electrode which has a carborundum point dipping into the mercury pool. If a sufficient voltage is

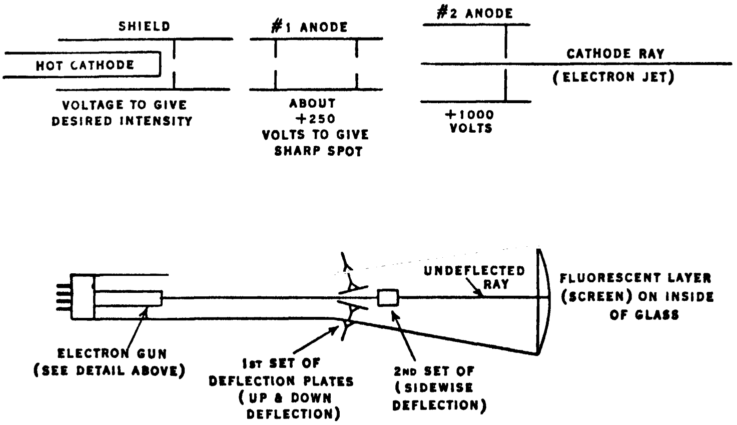

SHIELD
HOT CATHODE
VOLTAGE TO GIVE DESIRED INTENSITY
#1 ANODE
ABOUT +250 VOLTS TO GIVE SHARP SPOT
#2 ANODE
+1000 VOLTS
CATHODE RAY (ELECTRON JET)
UNDEFLECTED RAY
FLUORESCENT LAYER (SCREEN) ON INSIDE OF GLASS
ELECTRON GUN (SEE DETAIL ABOVE)
1st SET OF DEFLECTION PLATES (UP & DOWN DEFLECTION)
2nd SET OF (SIDEWISE DEFLECTION)

Fig. 4–40. Cathode-ray tube.

applied to this electrode, current passes between it and the mercury producing a small amount of ionized mercury vapor which triggers off the main discharge to the plate in a manner similar to the striking of any mercury arc, but this arc goes out on each negative half-cycle and stays out if the igniter has meantime been deprived of its ignition voltage. Thus the tube functions as the thyratron, but with a simpler and very rugged physical structure with a long life-expectancy. The momentary currents which such tubes can pass for control and welding purposes are extremely high. Their application to radio work is as yet limited.

4–26. Cathode-ray Tubes—The cathode-ray tube is ordinarily of vacuum type and should perhaps have been discussed sooner except for the fact that its action is more easily understood after some of the special types already mentioned. A typical construction appears in Figure 4–40. An electron gun emits a stream of electrons at high speed toward the other end of the tube where they strike the center of a round screen which is a layer of a material such as zinc silicate or calcium tungstate, capable of glowing when struck by electrons.

The electron gun of the cathode-ray tube consists of a hot electron-emitter (cathode), a grid to control the current-flow, and several anodes to direct this flow into a thin stream. The second and more positive anode usually has a small opening from which this stream emerges as from a nozzle, striking

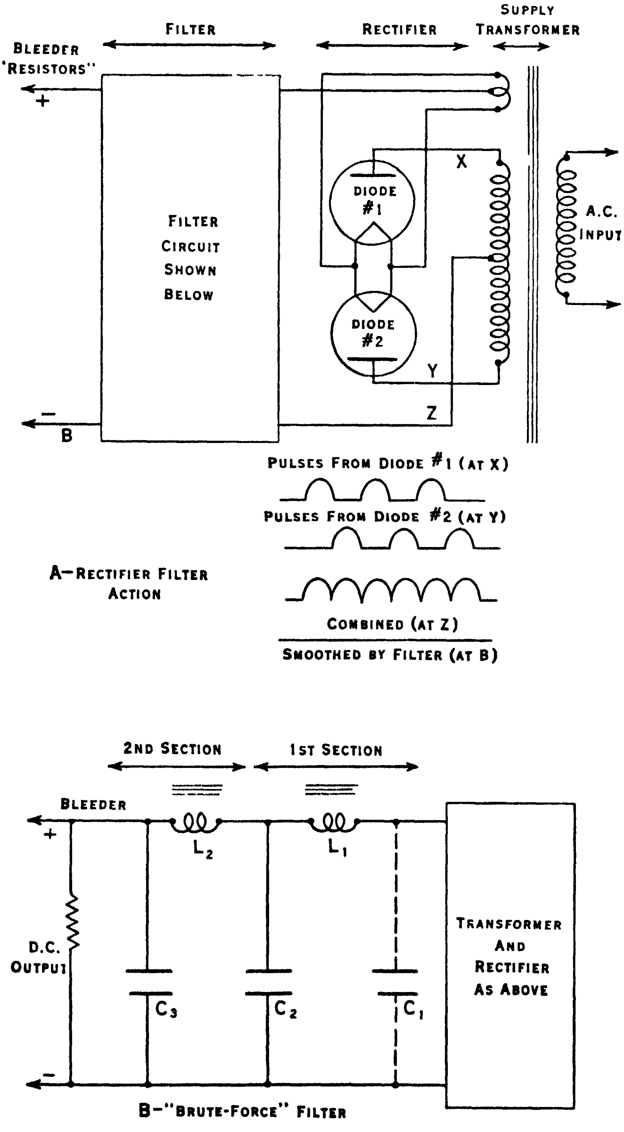


Fig. 4–41. Typical power supply rectifier-filter circuit.

the center of the screen unless deflected. Deflection is possible with the aid of either a magnetic or electrical field, since both affect electrons. Some cathode-ray tubes have no internal deflecting devices and are used with coils laid alongside the electron path; others have small deflecting plates sealed into the tube in pairs, the ray passing between them and hence being bent by any voltage applied to the pair. Two pairs are common to permit moving the ray in two directions.

Primarily the cathode-ray tube is a voltmeter (the beam bending proportionally to the strength of the electric or magnetic field), whose response is instantaneous, and which draws virtually no current. Hence it will work at high frequencies with small power. In addition it is nearly foolproof, enduring violent overvoltage without injury. The ability to move in several directions makes possible the drawing of curves and such special applications as television. For the radiotelephone station their greatest interest is in the ability to draw a moving picture of the modulation far more informative than many meters, and constantly up-to-date.

4–27. Power-supply Rectifiers and Filters—The commonest power source of plate voltage for receivers and small transmitters employs the circuit of Figure 4–41. The two diodes may be either in a single tube or in two tubes with their cathodes tied together. The action is explained by the figure, but various important considerations cannot be seen there.

(*a*) The transformer supplying a rectifier is delivering half-wave surges of abnormal wave form, hence its design departs somewhat from straightforward a-c practice; purchase from a supplier specializing in transformers for this particular use is advisable.
(*b*) The effectiveness of the smoothing (filtering) and the voltage stability are both very strongly affected by the design of the filter, for which simple rules are suggested.
(*c*) The tube life, especially for the mercury-vapor rectifier, depends on unequivocal adherence to certain rules of filter design and loading.

Before proceeding to filters we will review briefly the nature of the two types of diode rectifiers.

The high-vacuum diode, which is available in a wide range of sizes, suffers quick and permanent filament injury in the event of a serious overload as from a short circuit in the filter or load, or even from a moderate, maintained overload. It is possible for ruinous momentary overloads to exist even though the meter in the d-c filter output indicates a safe load.

The mercury-vapor diode is capable of handling large currents without excessive heating and hence is attractive in the larger applications. Its use in receivers has been attempted most unsuccessfully because of the noises created by the abrupt surge at the first part of each forward half-cycle. It is also necessary to guard against this in transmitters and to shield near-by low-power stages thoroughly. The mercury diode, because of the surge tendency and also because of its very low resistance, is even more easily injured by short current peaks than the high-vacuum diode. Since the mercury-vapor tube depends upon ionization of the mercury, any failure of this process results in concentrating almost the whole plate voltage at the filament surface which may lose all its active surface in a few seconds, minutes, or hours.

4–27a. Filters—Smoothing and Regulation—The conventional power-supply filter does not attempt to use tuned circuits but simply shunts large condensers across the rectifier output circuit and large iron-core choke coils in series with the rectifier output, as shown in Figure 4–41B, a method aptly called "brute force" by Ballantine but generally accepted as best for the problem of smoothing an output obtained by rectifying a.c. The essential requirements of such a filter are:

(*a*) It must contain enough capacitance and inductance to reduce the ripple to the desired extent and must avoid resonance with the supply frequency.
(b) It must not use too little inductance and too much capacitance (except at very low voltages), or tube-surges will result in the damage already mentioned, particularly in the case of mercury-vapor tubes.

Filter troubles ordinarily begin in the first filter section. Of course, this may be the only filter section used, particularly in a radiotelegraph transmitter. Resonance with the supply frequency is easily avoided if the first section has a henrys-times-microfarads product of 14 for a 60-cycle supply, or 20 for a 50-cycle supply, but this must not consist predominantly of capacitance unless the voltage and the load current are quite low—even when using a high-vacuum rectifier. If the filter has an input condenser (C_1), then the first choke L_1 should have a value of 20 henrys or better, with the input condenser not exceeding approximately 4 μf, and the second condenser of about the same value in the case of a mercury-vapor rectifier, or as large as desired for a high-vacuum rectifier, under normal conditions. With such a condenser-input filter, the high-vacuum rectifier tubes may be worked at the same load current as with a filter of the inductance-input type—that is one lacking C_1. However, the a-c voltage supplied to the tubes should not be greater than 75 percent of the voltage permissible with an inductance-input filter. Or, on the other hand, if the input voltage is kept the same, then the load current must be reduced 25 percent from that considered proper at maximum voltage with the inductance-input filter. In other words the *high-*

vacuum rectifier cannot work at maximum current and maximum voltage simultaneously when using a capacitance input filter.

TYPICAL RATINGS OF HALF-WAVE VACUUM DIODE RECTIFIER

	PERMISSIBLE LOAD CURRENT IN MILLIAMPERES	
	Filter with Capacity Input	*Filter with Inductance Input*
Plate volts (a.c.) 600	180	180
Plate volts (a.c.) 650	135	180
Plate volts (a.c.) 700	135	180
Plate volts (a.c.) 750	--	180

The regulation, that is, the voltage drop under load, is greater with the capacitance-input filter, but this type of filter produces a higher no-load output voltage for the same a-c input voltage. Thus it depends on the load whether a certain a-c supply voltage will produce a higher output voltage through a capacitance-input filter or an inductance-input filter. Where the load is light and steady, the condenser-input has an advantage. Where the load is heavy (30 percent or more of tube rating), and especially where it is variable, the inductance-input is preferred.

4–27b. Filters for Mercury-vapor Tubes—The above considerations are much more important for the mercury-vapor type of tube which may be used with a condenser-input filter *only if run at reduced load current and moderate voltage.* The antiresonance rule already given must be observed, and, if a condenser-input filter (strongly advised against) is used, it must also observe the rules already set down but with a *50 percent reduction* in load current.

Perhaps the most striking fact about this tabulation is the much smaller safe value of the first choke when using 3-phase rectification. The reason is that such a rectifier produces overlapping pulses; hence no tube looks into a currentless circuit, and cannot be subjected to a starting surge as severe as that in a single-phase rectifier with an equally small first choke. For high-power rectifiers polyphase rectifiers are invariably used because of the increased ease of filtering, decreased danger to tubes, and higher output voltage for the same tube strain.

4–27c. Filters—Regulation with Mercury-vapor Tubes, Filters for High-resistance Loads—The regulation effect of the filter on a high-vacuum diode has been mentioned. This effect is also present with the mercury-vapor diode, and the low resistance of the latter permits a filter action productive of superior regulation. To accomplish this, the first choke is made larger than required by the rules thus far set down for those cases where the load is of high resistance. Such loads, incidentally, *may* cause surging in tubes with the first chokes previously mentioned.

TABLE OF FIRST INDUCTANCES (L_1) TO PROTECT MERCURY-VAPOR DIODES AGAINST SURGES AND POOR REGULATION UNDER CONDITIONS OF HIGH-RESISTANCE LOAD. (Load resistance defined as d-c output voltage/d-c output current.)

Load (ohms)	*Recommended First Choke* (L_1) *(henrys)*
100,000	200
10,000	20
5,000	10

Note—Tabulation applies to single-phase, full-wave (2 tubes) only.

The high cost of a choke with such high inductance at light load, but large enough to carry full-load current, has led to the "swinging choke" popularized by F. S. Dellenbaugh. This is a choke designed to have a high inductance at light load but to undergo magnetic saturation under heavy load current, with consequent decrease in inductance. If the swing ratio is high, the choke *must* be designed for the load current, but if the swing is only 2:1 or 3:1 it may be used with some carelessness while providing improved results and lower cost, and permitting the power supply to work with either large or small load currents.

However, no mercury-vapor rectifier system should be operated entirely without load if avoidable. In all cases provide a drain equal to 5–10 percent of full load, through a bleeder resistance if necessary, or provide a no-current release to cut off the power supply whenever the load drops below such a value.

4–27d. Noises Caused by Mercury-vapor Rectifiers—Mercury-vapor rectifiers produce severe

TYPICAL MAXIMUM PERFORMANCE OF MERCURY-DIODE RECTIFIERS

	Relative Volts	D-c Load Amp	Filter Recommendations	
			Minimum L_1 (henrys)	Maximum C_2* (microfarads)
2 tubes, full wave, capacitance-input filter	1.25	0.5	See previous paragraphs on capacitance-input filter	
2 tubes, full wave, inductance-input filter	1.00	1.0	10	1
4 tubes, bridge, full wave, same filter	2.00	1.0	20	0.5
6 tubes, 3-phase, full wave	3.0	1.5	2	0.5

* May be increased in the same proportion as L_1 is increased.

noise in near-by receivers, and often in audio amplifiers apart from receivers, unless the rectifiers are prevented from surging. Capacitance-input filters are always troublesome and can seldom be quieted completely. The best remedy is an adequate input choke L_1, supplemented by shielding of the tubes and the entire supply, and sometimes r-f chokes of a few millihenries connected close to each plate. Buffer condensers connected across each tube may prove helpful. They must be a high-grade r-f type, suited to high d-c voltage, and of a capacitance about 0.001 μf.

4–27e. Effectiveness of Filtering for 1- and 2-Section Filters—Although the first filter section has the foregoing requirements for the sake of tube safety (except at reduced voltages and currents), the final filtering effect is brought about by the total amount of capacitance and inductance employed. The theory need not be gone into here. The following tabulation is a fair guide for most work.

TABULATION OF FILTERS FOR SINGLE-PHASE, FULL-WAVE POWER SUPPLIES (Either Vacuum or Mercury Rectifier Tubes)

Class of Load and Theoretical Percentage Ripple	*1-Section Filter Constant,* $(L \times C)$	*2-Section Filter Constant,* $(L_1L_2)(C_1 + C_2)^2$
Push-pull Class A audio stages—5%	20	130
Radiotelegraph transmitters—1%	100	650
Radiotelephone transmitters and audio stages—1/4 of 1%	400	2520
High-grade audio systems — under 1/10 of 1%	Impractical	6500
Low-level audio stages and bias supplies—1/20 of 1%	Above filters inadequate; 3 stages of filtering recommended.	

4–27f. Devices for Effecting Filter Economy—In many cases it is needless to filter the entire power supply output to the same degree. In a radio receiver the output stage may be a push-pull class A amplifier working at 300 volts, while the other tubes operate at 250 volts and draw small currents, and the screens of these tubes operate at 100 volts and draw still smaller currents. It is then economical to employ the 2-stage filter of Figure 4–41B, taking off the output-stage supply just beyond L_1. The first filter stage need smooth to only a limited extent, as the push-pull output transformer will buck out hum if the two tubes are reasonably matched. The effect is not completely attained in all receivers because of the practice of using the field coil of the loud-speaker as the first filter choke L_1, thereby introducing an objectionable hum unless the speaker is very inefficient at low frequencies. In better receivers the speaker field is used either as a second choke L_2 or is connected across the plate supply system after some filtering has been accomplished. The other tubes require only small currents; hence L_2 may be small and inexpensive, or may be replaced by a number of small resistors, one in each supply line, each followed by a condenser of moderate voltage rating, in place of a single C_3. The various branch-line resistors are proportioned to produce the proper voltage drop in the d-c supply, in addition to acting as ripple filters. A danger of such filter systems is that, if they are operated with the receiver tubes removed, full voltage will be delivered to all the condensers, and as those beyond the resistors are not intended to stand this strain, breakdown may result.

4–28. The Electron Tube in Tuned Circuits—Many electron tube effects are obtained by their use in association with tuned circuits, which thus far in this manual have been assumed rather than explained. Nor is it necessary now to have in mind more than a few basic points concerning tuned circuits:

(*a*) A mechanical tuned system (piano string, tuning fork etc.) has inertia because of weight and elasticity due to the springiness of the material. Similarly an electrical tuned circuit has electrical inertia (called inductance), and electrical elasticity due to the capacitance of the circuit. In its simplest form an electrical tuned circuit consists of a coil (inductance) across which is connected a condenser (capacitance).

(*b*) Both mechanical and electrical tuned circuits can be made to oscillate (vibrate) by a single impact, as in a piano, or they can be made to vibrate by a series of small impulses recurring at their own natural frequency, as a piano string responds to a singing tone. Other tones will cause response only if near the natural frequency of the tuned piano string. The string's response may be made less discriminating (less sharp) if its free vibration is somewhat obstructed. Similarly an electrical tuned circuit becomes less discriminating if electrical resistance is increased. We then say that it tunes broadly, or that it is less *selective*.

(*c*) Since the frequency of a tuned circuit depends on the size of the inductance and capacitance, we have the ability to change this frequency by changing either the inductance or the capacitance; consequently, we change the frequency of an associated tube's operation whether it be amplifying or oscillating. This is called tuning.

(*d*) The frequency of a tuned circuit also depends to some extent on the coil resistance and *any* associated devices, which are called loads. Even the associated tubes are themselves loads on the tuned circuits and may greatly modify the tuning.

Of most immediate interest is the use of tuned circuits in radio receivers and transmitters.

4–29. Radio Receiver Systems—If the foregoing pages have been understood, present-day radio receivers will not appear strange, for they consist of devices already mentioned, such as radio-frequency amplifier stages to strengthen the signal, a detector or demodulator to make the signal audible, and an audio amplifier to make the sound louder, together with an automatic volume control to limit the changes in output should the signal fade. In most cases the receiver is tunable so as to respond to signals of different frequency, and there are usually provided manual controls of tuning sharpness, audio fidelity (tone control), and sensitivity. There also may be an automatic frequency-control arrangement for completing the tuning electrically when the receiver is set approximately to a station's frequency.

Despite the obvious variety possible, there are only a few fundamental receiver types in present use. These include the popularly called "tuned radio frequency," "superheterodyne," and "super-regenerative," none of which is a distinct type since combinations are possible and customary. However, the following discussion shall follow popular classification.

4–29a. The Tuned Radio-frequency Receiver—This system consists of a detector, preceded by one or more stages of tunable r-f amplification to strengthen the signal before it reaches the detector from where it customarily, though not necessarily, goes through one or more stages of audio amplification before being delivered to the loud-speaker or headset. The r-f stages invariably employ tetrode or pentode tubes, and the voltage gain per stage varies widely with the frequency from well over 100 times at low frequencies to almost nothing at the frequency limit of the tubes. The voltage amplification is affected by the L/C ratio of the tuned circuits and rises with this ratio. Both the gain and the selectivity of the successive stages are multiplied together for the final result, except when the system departs from true cascade amplification through undesired interstage couplings and stray pickup of the original signal. These effects are minimizd by shielding the tubes, coils and connecting wires and by resistance-capacitance filters in the power leads feeding them.

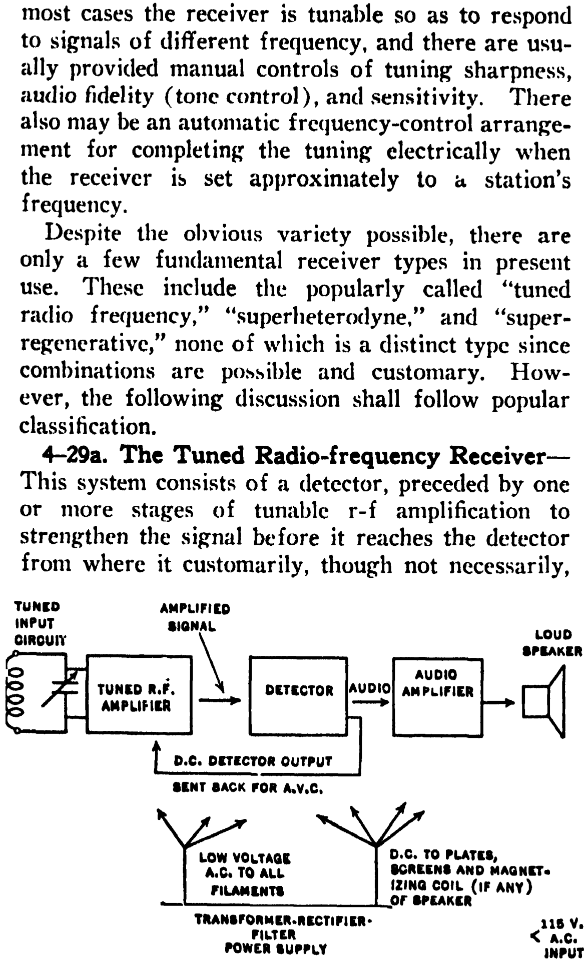


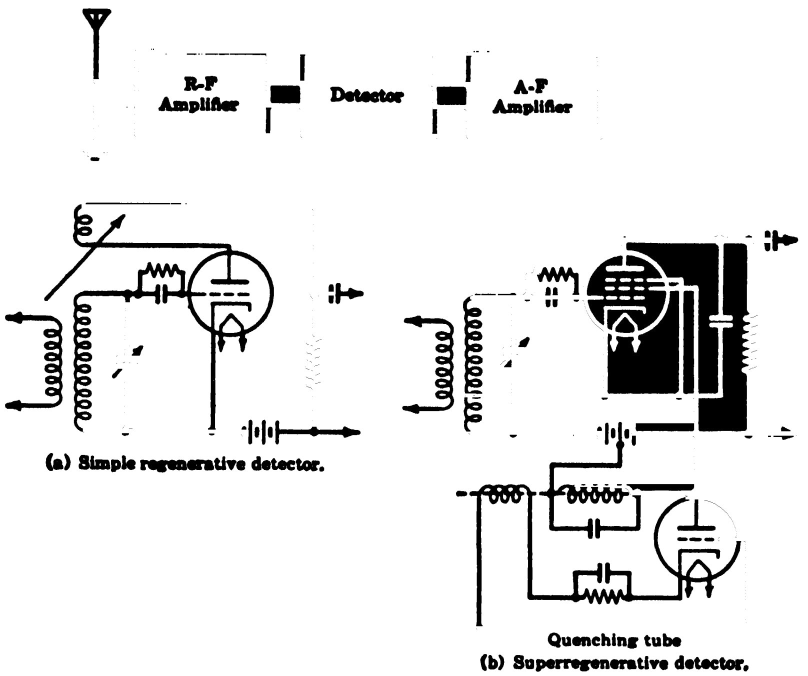
Fig. 4–42. Typical tuned radio frequency receiver.

When made for high gains and high selectivity, the TRF receiver is costly because of the necessity of aligning five or more variable condenser sections to operate exactly together, and continuing to do so despite age, temperature, and mechanical shock. It is this element of high cost which causes the superheterodyne to be preferred where high gain is desired or high selectivity imperative, and at least one of these two requirements applies to most present-day reception. Where interference is low and fidelity of reproduction is desired, the TRF type should be given serious consideration.

The detector-audio receiver is an obsolete type similar to the TRF receiver except that the r-f amplifier is omitted. Its only merits are simplicity and economy, but its lack of sensitivity and selectivity makes it unusable in the present crowded communication and broadcast bands. The performance of the detector-audio receiver can be greatly improved by employing a regenerative detector, Figure 4–43A, in which case the receiver is known as an autodyne or regenerative receiver. Such receivers have been quite popular in the past but have the serious disadvantage of causing interference due to radiation at the frequency at which they are operating. This radiation can be eliminated by employing a stage of r-f amplification preceding the oscillating detector.

4–29b. The Superregenerative Receiver—In an attempt to increase receiver sensitivity, there was devised by Major E. H. Armstrong the so-called superregenerative receiver, which is a circuit for greatly increasing the modulated signal gain of the regenerative detector.

The usual limitation of such detectors is that just as the gain is becoming worthwhile the regeneration runs away and the tube oscillates, whereupon it is worthless as a detector of modulated signals. However, during the instant of going into oscillation the gain is enormous and much work has been done to capture and maintain that condition. Failing this, an alternative scheme is to allow the detector to run through the transient high-gain condition, then bring it back and let it start over again—repeating the performance so rapidly that the resulting flutter is above audibility—or at least so high as to be unobjectionable. This is the principle of the super-regenerative receiver. It may be carried out by modulating the tube at a superaudible rate—for instance by adjusting the tube to oscillate strongly at the signal frequency, say 1000 kc, and then feeding into its grid a rather strong 30,000 CPS voltage which shall have the effect 30,000 times each second of blocking the oscillations and compelling the tube



(a) Simple regenerative detector.

Quenching tube
(b) Superregenerative detector.

FIG. 4–43. Regenerative and superregenerative receivers.

to start over, thus traversing the high-gain regenerative region again. In this case the 30,000-cycle supply would be known as the *quenching frequency*. While 30,000 cycles is inaudible and thus unobjectionable, it unfortunately does not provide the best gain except at quite short waves—the tube does not have enough time to "work up." A lower quenching frequency gives much higher gain, but unfortunately lower pitches are audible and to filter them out damages the audio output. Thus the present use of the superregenerative detector is largely in very high-frequency range (1 to 10 meters) where there are a great many oscillations per quenching even if the quenching frequency is made inaudible. The superregenerative receiver is characterized by a strong noise background whenever signals are weak.

The superregenerative detector has a rather pronounced threshold value, that is, signals below a certain strength are simply dropped as by a QAVC system. In fact the superregenerative detector in itself acts as a very effective QAVC system so that a signal which is gradually strengthened pops into hearing rather abruptly, gains slightly in strength and thereafter holds steady even though increased hundreds of times.

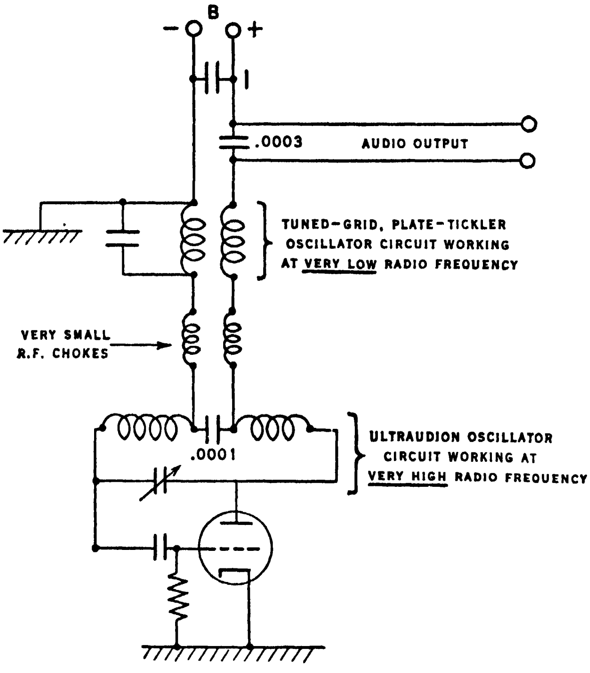
Both the quenching frequency and the signal frequency may be generated by the detector tube itself, Figure 4–44, or separate tubes may be used for each function, Figure 4–43B.

One of the pronounced disadvantages of the superregenerative detector is that it tends to radiate a rather wide frequency band because of its strong oscillation and the frequency wobbles due to the quench frequency modulation. To minimize this effect such detectors should be preceded by a tuned r-f amplifier. Every effort must be made to secure some gain in this r-f system, else the noise-to-signal ratio is increased. This is not difficult with modern tubes at very short wave lengths.

4–29c. The Superheterodyne Receiver—In Section 4–29a it was stated that the amplification of an r-f stage decreases as the frequency increases. Thus there is no difficulty in attaining large amplification in each stage at a frequency of, for example, 500,000 cycles (600 meters), but at a frequency of 30,000,000 cycles (10 meters) the stage gain may be extremely small. This gain can be raised by regeneration in the r-f stage, but the result is instability if more than one stage is used. It would therefore be a decided advantage if *all* signals could be fed through a low-frequency amplifier before going to the detector and audio system. This necessarily involves translating signals of all frequencies to a low frequency. While there are several possible schemes, the most tractable of them consists of translating all the signals to the *same* low frequency so that the amplifier may be of fixed tuning. The merit of fixed tuning is a double one:

(*a*) The mechanical complexity is vastly reduced.

(*b*) Since the tuning capacitance need not cover a wide tuning range, it may be very small, permitting the use of a large coil, that is a higher L/C ratio and better stage gain. The entire


B
−
+
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AUDIO OUTPUT
TUNED-GRID, PLATE-TICKLER OSCILLATOR CIRCUIT WORKING AT VERY LOW RADIO FREQUENCY
VERY SMALL R.F. CHOKES
.0001
ULTRAUDION OSCILLATOR CIRCUIT WORKING AT VERY HIGH RADIO FREQUENCY

FIG. 4–44. Super-regenerative detector oscillating at two widely different frequencies.

tuned circuit may then be put in a metal can, preventing interstage coupling to a considerable extent.

Such a system is called a *superheterodyne* or supersonic heterodyne and was originally devised by Major E. H. Armstrong. The essential circuits are shown in Figure 4–45. The intermediate-frequency (or i-f) amplifier is the low-frequency amplifier mentioned. It commonly works at a fixed frequency in the region of 100 kc to 40 mc, the choice depending upon the nature of the service. The number of stages in this amplifier ordinarily ranges from 1 to 4, 2 usually being adequate and easily stabilized. The interstage coupling devices are transformers, commonly made with iron-dust cores, which give improved coils at these relatively low r-f values.

It remains to describe the translator or converter which consists of an oscillator and a rectifier-amplifier, sometimes unfortunately called a first detector. The function of the translator is to translate the incoming signal to a low-frequency signal suited to the i-f amplifier. This is done as follows:

If two frequencies, x and y, are mixed and then passed through a rectifier, there will be found in the rectifier output the following frequencies:

(*a*) The original frequency x.
(*b*) The original frequency y.
(*c*) A new frequency equal to $y + x$.
(*d*) A new frequency equal to $y - x$.

In the superheterodyne the incoming radio signal is the x frequency, while the y frequency is supplied by a tunable oscillator in the receiver. No use is made of the $y + x$ frequency which is discarded, as are both of the original frequencies after passing through the translator. This leaves the $y - x$ frequency, which is quite evidently a lower frequency as desired. It is evident that by adjusting the oscillator frequency we can make $y - x$ any frequency desired—for instance, the frequency of the i-f amplifier. Let us assume that the i-f amplifier works at 465 kc. Then if y is 465 kc greater than the incoming signal, there will come from the rectifier a frequency equal to 465; hence this frequency will enter the i-f amplifier, thence the detector and audio system, and the desired translation will have been concluded satisfactorily.

The important point is that such translation can be accomplished without damage to the modulation. That is, the original modulation can, in effect, be transposed to a new carrier. The complete tuning process consists of adjusting the oscillator to translate the desired signal to the intermediate frequency, and adjusting the tuned input circuit to accept this signal. These interlocking operations are facilitated by coupling the two tuning condensers to the same control knob. It is beyond the scope of this discussion to explain the design of the circuits which permit the oscillator circuit to maintain the desired difference in tuning as the control knob is turned.

The actual oscillator and rectifier-amplifier may take a widely assorted combination of forms, of

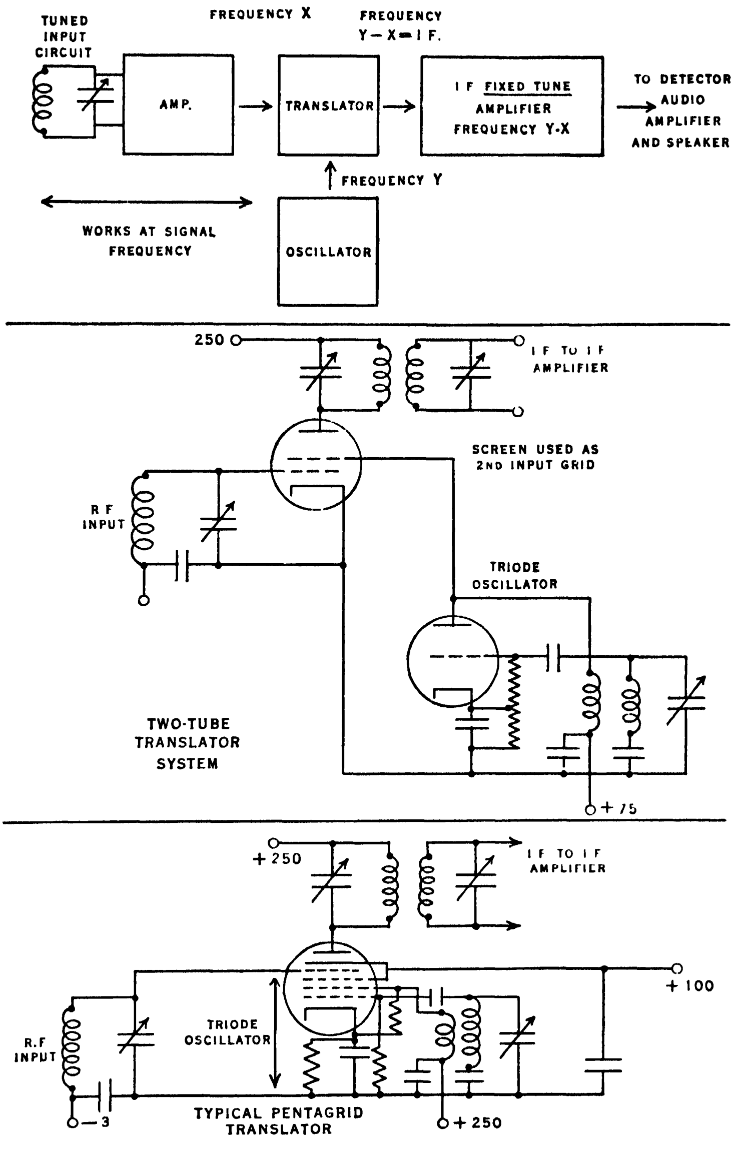

Fig. 4–45. The superheterodyne receiver.

which the representative forms in Figure 4–45 differ principally in that the lower one utilizes Dow electron-coupling between the triode oscillator section and the tetrode amplifier-rectifier section.

4–29d. Pre-selection—The performance of a superheterodyne may be improved by placing 1 or 2 stages of tuned r-f amplification ahead of the translator. This is not for lack of gain in the i-f amplifier, which may be made extremely high. Rather it is because of two effects not as yet mentioned. One of these is that a translator tends to contribute a considerable amount of a distressing type of noise sometimes described as "superheterodyne shush" unless the signal is moderately strong to begin with. (This is not the entire story of "shush" by any means as it is strongly dependent on the design of the translator and the use of a proper oscillator voltage.) The other effect is that a translator preceded by merely a single tuned circuit is unable to reject strong signals near the wanted signal, and while these will subsequently be rejected by the high selectivity of the i-f system, there will remain permanent injury in the form of cross modulation, which is modulation superimposed onto the i.f. from the undesired signal. Thus improved front end selectivity is indicated, and while this can be provided by merely adding more front-end tuned circuits, such a procedure wastes some of the wanted signal and hence damages the signal/noise ratio, which effect may be avoided by using not merely an additional tuned circuit but also an amplifier tube—which is to say, a stage of tuned r-f amplification. Thus the superheterodyne in its better forms has at least 3 tuning condenser sections.

Two other types of interference can also be reduced by the increase of front-end selectivity which a preselector affords. The first is interference from a transmitter operating near the intermediate frequency of the receiver. This type of interference is heard at almost the same intensity all over the dial, though it may be suppressed when a strong station is tuned in. The experience of two manufacturers of entertainment receivers is that this difficulty rarely arises more than 100 miles from the interfering station and that a single station can be eliminated satisfactorily by a simple wavetrap.

The tuned preselector is of considerable effectiveness in eliminating another variety of interference which is due to the inherent tendency of a superheterodyne to respond to two widely separated frequencies, the unwanted or "image" frequency being separated from the "wanted signal" by the amount 2 × intermediate frequency. Thus if the intermediate frequency is 500 kc and the oscillator is set at 2500 kc it is clear that we intend to receive a signal at 2000 kc ($2500 - 2000 = 500$) but if it chances that there is a fairly strong station at 3000 kc it will also be heard unless there is enough selectivity ahead of the translator input grid to prevent the 3000-kc signal from reaching that grid. (Note that $3000 - 2500 = 500$; also that $3000 - 2000 = 2$ i.f.) At medium waves any fairly good preselector practically eliminates this effect, but at short waves excellent design is necessary unless the i.f. is higher than 500 kc. The image response is generally weaker than the response when the receiver is tuned to the operating frequency of the station.

4–29e. Automatic Frequency Control (AFC)—In the superheterodyne receiver it becomes practical to use a form of semiautomatic tuning which corrects manual inexactness in tuning, provided the device is well maintained and, further, provided the wanted signal is fairly well above interfering signals on adjacent frequencies or has manually been tuned in well enough to create a similar effect upon the receiver. These devices appear in various forms in transoceanic communication receivers, and in more commonplace receivers also, but all depend upon altering the frequency of the translation oscillator slightly by changing its load or one of its electrode voltages in such a manner as to cause the oscillator to shift in the direction required to shift the signal into the i-f channel. One of the numerous ways of deriving the required control from the received signal is shown in Figure 4–46. Here a discriminator circuit, tuned to the intermediate fre-

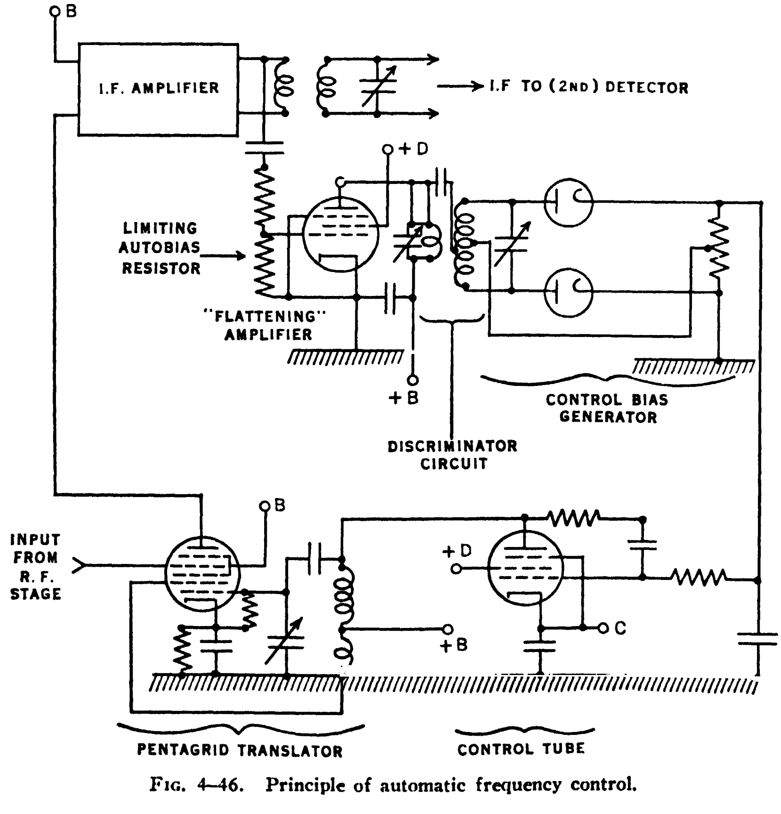

Fig. 4–46. Principle of automatic frequency control.

quency, is fed by both magnetic and capacitive coupling. If a signal is tuned correctly the two ends of the circuit are equally affected and the associated rectifiers give forth equal and opposite d-c voltages, which oppose each other and nullify. If the signal is mistuned one end of the circuit picks off more of it and the output of the associated diode predominates. Thus the amount and direction of the d-c output voltage from the diodes are related to the direction and amount of mistuning *and the signal strength.* The last factor confuses the system, hence must be minimized by a preceding limiter tube, that is, a tube unable to respond to more than a fixed amount. In any case the d-c voltage from the diodes is now fed to the grid of a control tube, in addition to (or in opposition to) the fixed bias of that tube. The control tube is enabled to govern the oscillator frequency by virtue of, the fact that the plate of the control tube is connected to the tuned circuit of the oscillator. The exact manner in which the control becomes effective depends on the designer and his choice of either a single control tube or a pair placed back to back, but in general the control tube plate circuit acts either as a varying load or as a source of a varying r-f voltage originally derived from the oscillator but changed in phase and amplitude by the control tube before being returned to the oscillator. Either action changes the oscillator frequency, but it is an exacting design task to obtain changes of the proper magnitude.

4–29f. Receiver Selectivity—The selectivity of a receiver, that is, its ability to reject unwanted signals, depends on both the number and the effectiveness of the tuned circuits (see Figure 4–47). In the tuned r-f receiver this number is equivalent to the number of tuning-condenser sections while the effectiveness of the circuits (reactance/resistance) is limited by the fact that the L/C ratio changes with tuning. In such systems, if more than one r-f stage is used, it is accordingly worthwhile to use a number of tuning ranges (sets of coils) and a small tuning capacitance, and to look carefully to sources of stray capacitance and losses—that is, solid dielectrics not essential to the structure. Where high performance is wanted, this leads to the elimination of coil-switching schemes in favor of plug-in coils or a movable coil tray sliding under fixed contacts, rather than fixed coils with a gang switch.

In the superheterodyne receiver the selectivity problem is far easier for two distinct reasons. First, the receiver may easily employ many tuned circuits, most of which have no moving parts (being in the i-f system) and may thus be designed for high selectivity. Second, there is a sort of unearned selectivity increase due to the fact that the intermediate frequency is lower than the signal frequency, hence a given mistuning represents a larger percentage and is more energetically refused. Thus if the signal is at 2000 kc (150 meters) and is interfered with by a station on 2010 kc, a TRF receiver will find difficulty in separating the stations as this is but ½ of 1 percent difference. However, if the signals are both translated to 500 kc, this same difference is 2 percent. It is easily possible to make a superheterodyne too selective to pass the higher frequencies of music. Therefore many receivers are provided with a control of i-f selectivity to permit wide-band reception on those occasions when interference does not prevent it. These circuits may operate by changing the coupling in the i-f transformers, by variable resistors, or by auxiliary circuits—in some cases even by discarding the superheterodyne system and feeding from the r-f preamplifier directly into the so-called second detector.

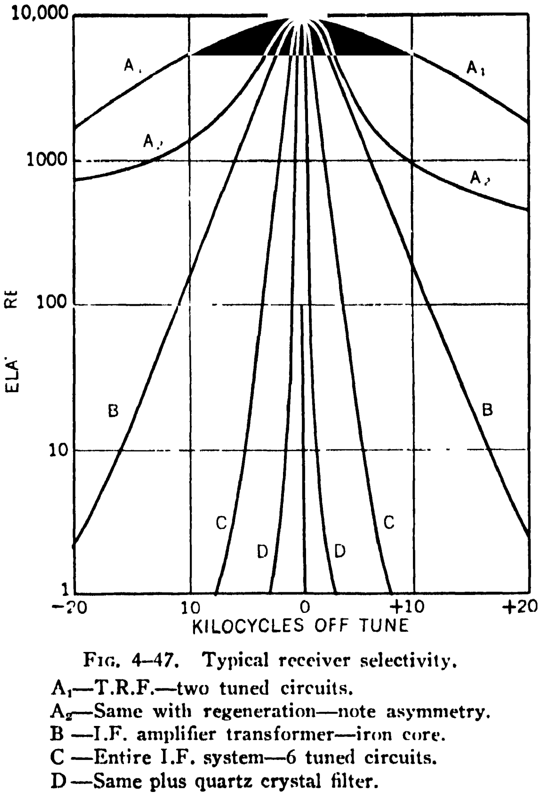

Fig. 4–47. Typical receiver selectivity.
A_1—T.R.F.—two tuned circuits.
A_2—Same with regeneration—note asymmetry.
B —I.F. amplifier transformer—iron core.
C —Entire I.F. system—6 tuned circuits.
D —Same plus quartz crystal filter.

4–29g. Crystal Filters in Superheterodynes—Inasmuch as a quartz crystal plate is suitable for oscillator control simply because it is the equivalent of a very sharply tuned circuit, it may also be used as a tuned circuit—in fact the original use of such plates (due to Dr. W. G. Cady) was just that, the oscillator-control by quartz plates being a later invention by Dr. G. W. Pierce.

Where extreme selectivity in a superheterodyne is desired, it may be attained by using a quartz plate as one tuned element in the i-f amplifier, the plate having the proper thickness to resonate at the intermediate frequency. It is necessary to place the quartz between two metal plates in order to make it operative, and as this comprises a condenser (which is *not* selective) the system is vitiated unless the capacitance effect can be balanced out. Balancing may be accomplished by extending the circuit to form a small balanced Wheatstone bridge as in Figure 4–48. This is the Robinson "stenode" receiver, which can be designed and adjusted to pass very little beyond a band 50 cycles wide—a selectivity too large for voice or music reception, but at times advantageous for telegraphic reception through noise—though at the expense of some signal distortion occasioned by the inertia of the crystal. Robinson used such a system for music reception by employing an audio correction amplifier designed to give abnormal high-frequency response. He also observed that by slightly unbalancing the crystal network it was possible to eliminate one sideband of a modulated signal, the mathematical explanation of which has been provided by R. R. Batcher. Similar asymmetrical adjustments of the crystal bridge (see Figures 4–48 and 4–51) are at times used to reduce an unwanted telegraphic signal near a wanted one, this effect having suggested the name "single signal receiver." Under conditions of extreme interference voice signals are occasionally intelligible with the stenode when not intelligible otherwise, and so-called communication receivers may be used with the crystal switched in on voice signals, the lack of an audio correction system being offset by the fact that such receivers usually have midget loud-speakers which respond more strongly at higher audio frequencies—one case where such a speaker may be of advantage.

4–29h. Useful Receiver Sensitivity—While it is not within the scope of this chapter, one may digress sufficiently to point out that receiver sensitivity is useful only insofar as it is attained without the inclusion of noise, whether received from the antenna, from the power supply, or generated in the tubes of the receiver. The prime source of tube noise is lack of amplification in the early stages of the receiver—that is, before tube and other noises have an opportunity to contaminate the signal. Thus the advantage of a tuned r-f stage ahead of all other tubes assumes added importance. Keeping the signal above the noise is of paramount importance in all successful amplification whether in receivers, transmitters, public address systems, or at the low levels of a high-quality microphone.

4–29i. Receivers for Unmodulated Signals—Radiotelegraphic signals are usually unmodulated, hence do not produce any audible sound when passed

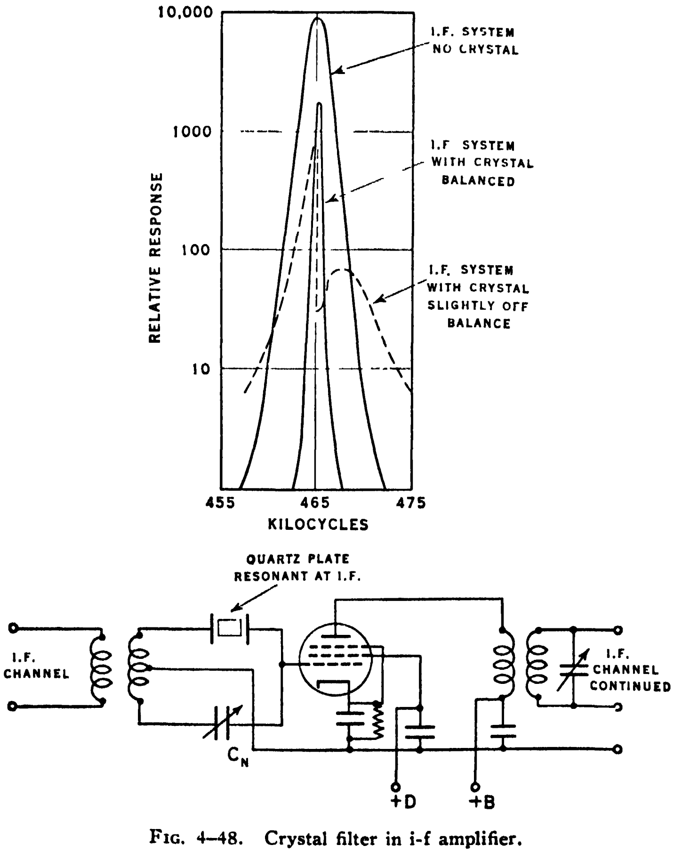

Fig. 4–48. Crystal filter in i-f amplifier.

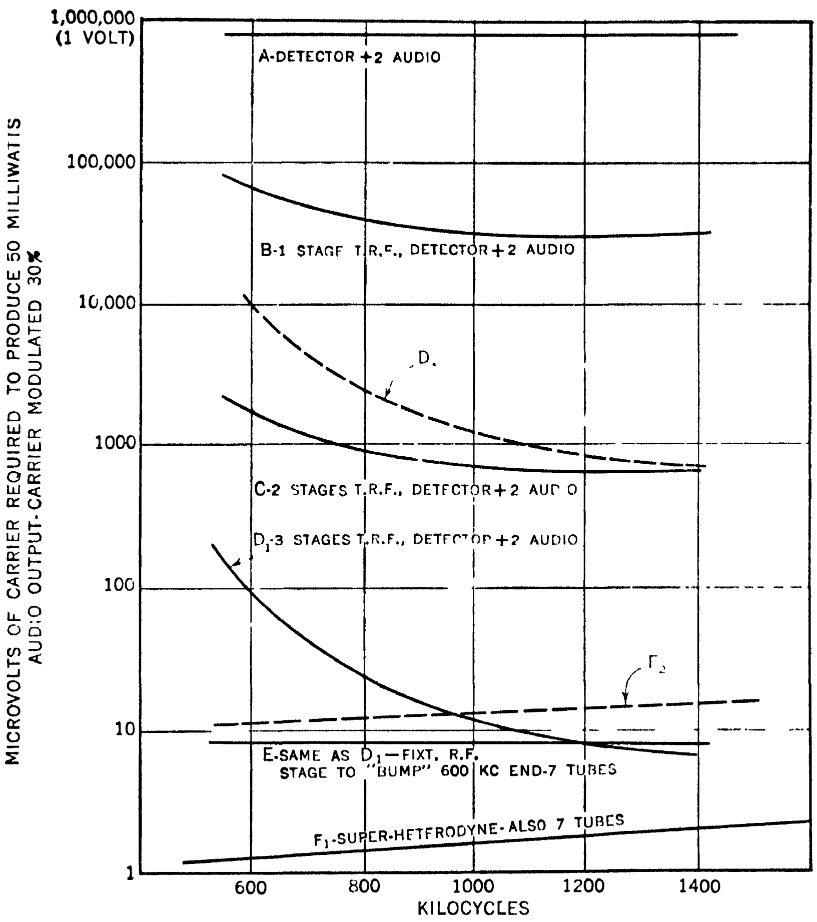

Fig. 4–49. Sensitivity of typical receivers in the 600–1600 kc. tuning range. Performance at higher frequencies is always poorer; curves D_2 and F_2 correspond to D_1 and F_1 but are for the range of 6000 and 14,000 kc.—i.e. ten times the frequency.

through the receiver systems thus far described. However, the unmodulated carrier does, of course, amount to a stream of energy arriving at the detector whenever the transmitting key is closed. If the receiver is equipped with an adjustable r-f oscillator tuned to, for instance, 1000 cycles above the frequency at which the signal reaches the detector, there will result an action the same as that described for the superheterodyne translator, and from the detector there will emerge a 1000-cycle tone sustained as long as the sending station key is held closed. When the incoming signal ceases, the local oscillator continues—but it also represents no sound when working alone. Such an arrangement is known as a *beatnote oscillator* or *heterodyne*. The translation here is from radio frequency to audio frequency instead of a high radio frequency to a low radio frequency, but this is merely a difference in the size of

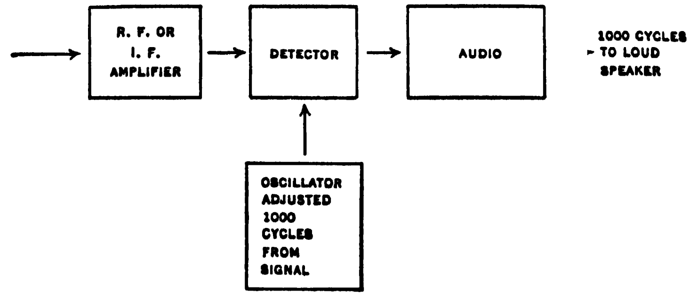
R. F. OR I. F. AMPLIFIER
DETECTOR
AUDIO
1000 CYCLES TO LOUD SPEAKER
OSCILLATOR ADJUSTED 1000 CYCLES FROM SIGNAL

Fig. 4–50. Hetereodyne method of beatnote reception.

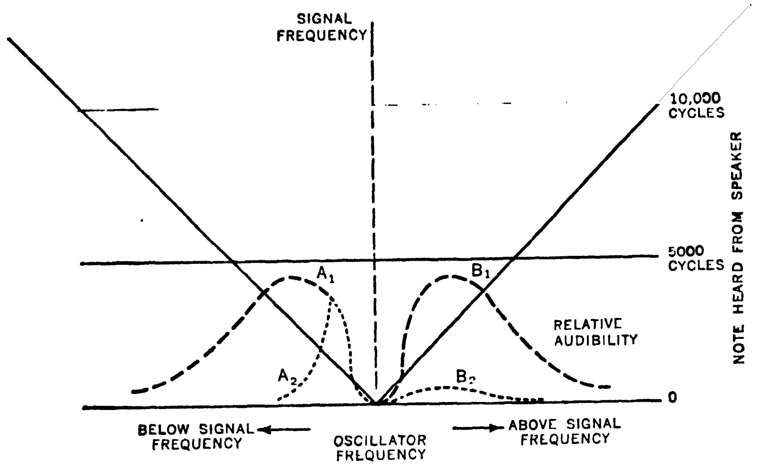

FIG. 4–51. Beatnote or pseudo selectivity.

the jump—not in its nature. Since the output in this case is audible, the effect of oscillator changes can be heard.

The heterodyne oscillator of a TRF receiver must be tunable as it must be kept the proper distance from the desired signal, as must the oscillator of a detector-audio system which lacks an r-f amplifier. For this reason it is convenient to make the detector itself oscillate and then provide either its tuned circuit or that of the r-f system with a small trimming condenser to effect the desired 1000 cycles staggering or difference in tuning. Frequently this is omitted, as the TRF system is usually broad enough so that it may be mistuned by that amount (thus tuning the oscillating detector to give the desired beatnote) without material loss of signal strength.

The oscillating detector is also called an autodyne detector and is provided with a control of the intensity of oscillation in order to obtain best sensitivity.

In the case of a superheterodyne receiver the beatnote oscillator is, of course, additional to the translation oscillator, but does *not* need to be tunable since it works against the fixed intermediate frequency and requires adjustment only to compensate for heating and aging drifts or to suit the fancy of the user as to beatnote pitch. It is accordingly operated at a frequency near the i.f. and a limited range control is provided.

4–29j. Tone Selectivity in Telegraphic Receivers—If interference is moderate, successful telegraphic radio reception may be accomplished with autodyne receivers having two or even one tuned circuit by taking advantage of the tone selectivity or pseudo-selectivity (Figure 4–51). Detuning changes the beatnote and drives it out of audibility at a rate far in excess of the 1 or 2 tuned circuits' ability to reject an off-tune signal. For instance, we may say that a beatnote has become essentially inaudible at 15,000 cycles, which is but 1/10 of 1 percent of the 15,000 kc represented by a 20-meter signal—a difference against which a single tuned circuit working on legitimate selectivity is ineffective. To obtain the same selectivity by pure tuning would require a good superheterodyne with perhaps nine tuned circuits. This receiver would, to be sure, have a sensitivity above that of the autodyne receiver, and would also be much more selective against *strong* signals, for tone selectivity is not effective against detector overload, nor against modulated signals, whereas tuned-circuit selectivity also wards these off.

In the simple receiver just discussed, the signal would be heard at two adjustments (A_1 and B_1, Figure 4–51) with equal intensity. In a good superheterodyne, especially one with a crystal filter, this would *not* take place since only one of two peaks can take place when the signal is tuned exactly into the highly selective i-f system. The effect may be further exaggerated by unbalancing the crystal, giving curve A_2 B_2.

The use of crystal-filter i-f systems is fairly common in radiotelegraphy and has already been discussed.

4–29k. Other Features of Telegraph Receivers—Telegraph receivers are seldom required to produce high audio outputs, hence may have a relatively small audio system without power audio tubes. Their automatic volume control systems also differ from those of receivers intended for modulated signals, because telegraphy consists of cutting off the carrier entirely, which would cause an ordinary AVC system to go to maximum sensitivity and thus inject bursts of noise between the dots and dashes, also to start each dash very loudly and then fade the latter part. To avoid these effects the AVC system may be made slower in action by using larger capacitances. QAVC, described in section 4–14, is helpful.

The telegraph receiver is ordinarily benefited by a deficient audio response at low and high frequencies, thus suppressing noise and interfering signals while favoring tones in the region of 1000 cycles. Where receivers are used for both telegraphy and voice, a peaked audio filter is occasionally provided, with a switch for disconnecting it when receiving voice or music.

In commercial services it is essential that the signal always be found near the same point on the tuning scale and great care is taken to design the tuned circuits (especially the translation oscillator circuit) for permanence by the use of non-aging materials, mechanical construction far sturdier than that employed in broadcast receivers, and by so proportioning and placing the components to minimize frequency shifts of the heating-drift type, whether due to the heat of the tubes or external sources. No detail need be given on these points, for only the manufacturer has control of the matter and it does not fall within the scope of normal receiver adjustments and alterations such as the reader of this manual may be expected to make.

CHAPTER 5

AMPLIFIERS AND OSCILLATORS

Vacuum tube amplifiers, owing to their many applications, are commonly classified in a number of different ways. One method of classification identifies amplifiers according to the circuit employed (such as cathode follower, resistance-coupled, etc.). Another method classifies amplifiers according to their application (such as modulator, voltage amplifier, etc.). Still another method classifies amplifiers according to the frequency range or operating frequency of the amplifier (such as frequency tripler, intermediate-frequency amplifier, etc.). Finally, amplifiers are often classified according to the portion of the cycle of the signal voltage during which plate current flows. Three general classifications, identified by the alphabetical designations A, B, and C, are in wide usage. An intermediate classification, AB, is also very frequently encountered.

In this chapter, amplifiers are to be discussed according to the last-mentioned method of classification, that is, according to the portion of the cycle during which plate current flows.

5–1. Fundamentals—In any vacuum tube amplifier—whether triodes, tetrodes, or pentodes are used—the control-grid input voltage (commonly called the signal voltage or excitation) is applied between the control grid and the cathode. It is almost always an a-c voltage and usually acts in series with a d-c voltage called the grid bias.[1] Variations in the instantaneous total grid voltage are produced by the signal voltage, and these changes cause corresponding changes in the plate current. These fluctuations of plate current develop a-c power in the load or output circuit. The general arrangement of the essential elements is shown in Figure 5–1.

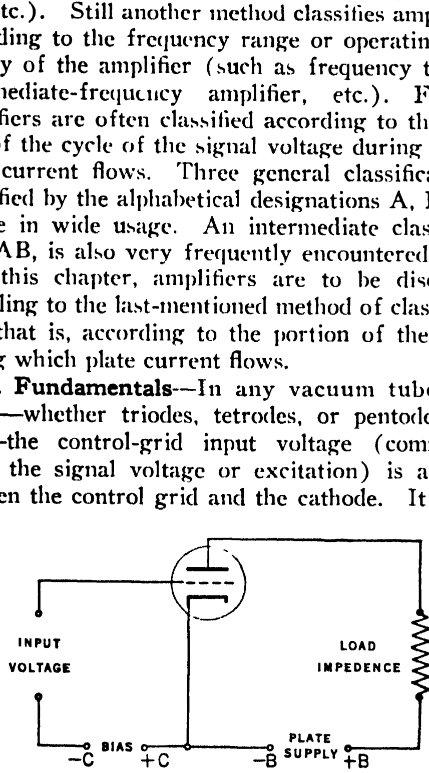

FIG. 5–1. Essential elements of an amplifier.

Since the signal-voltage and the plate-circuit fluctuations are alternating voltages and currents, and the bias and plate voltages are direct, it is usual to employ blocking condensers and choke coils in order to separate the direct and the alternating components. Figure 5–2 shows one of the many circuits in which blocking condensers and choke coils separate the input and output a-c circuits from the bias and plate-supply d-c circuits. It is essential that the choke coils possess high impedance at the frequencies to be amplified. For r-f amplifiers, inductances of from 1 to 100 millihenrys are needed, and air-core coils are commonly employed. For intermediate radio frequencies somewhat higher values may be desired, and coils of special iron-dust core construction are commonly used, although air cores may be employed. For audio frequencies, iron cores (or cores of high-permeability alloy steel such as permalloy) are essential to obtain the necessary inductance without requiring excessively large coils. Values of from 1 to 500 henrys are common. The design of such coils is very important because low inductance will result in poor amplification at low frequencies, while high hysteresis losses or excessive distributed capacitance will reduce amplification at the higher frequencies.

The capacitance of blocking or by-pass condensers must be large enough to keep the reactance low [2] at the lowest frequency to be amplified. At the same time it is frequently (but not invariably) necessary that the capacitance from either side of the condenser to ground be kept low, or a loss of amplification may be experienced. Radio-frequency amplifiers use values ranging from 0.00001 to 0.002 μf, depending on the frequency and the value of other circuit elements. Audio amplifiers use larger values, 0.01 μf up to as much as 50 μf.

5–1a. Triodes, Tetrodes, and Pentodes—Figures 5–1 and 5–2 have been drawn to show a triode tube. Tetrodes and pentodes operate in the same manner. The fixed voltages on the screen grid and, in a pentode, the suppressor grid are applied for the sole purpose of obtaining the desired relations between grid voltage and plate current. All discussions, equations, and diagrams to follow apply equally to triodes, tetrodes, and pentodes, except where specifically mentioned. Figure 5–3 shows a pentode amplifier. Note that the most active elements (grid, cathode, and plate) are connected exactly the same as in a triode amplifier. Both screen and suppressor grids are given d-c voltages, but

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[1] The d-c bias and a-c signal are connected in series, adding at some moments, subtracting at others.

[2] This means low *as compared to the other circuit elements.* Thus in an audio amplifier a plate-to-grid coupling condenser is of "low" impedance as compared to a 100,000-ohm plate resistor and a 500,000-ohm grid leak if it be of 0.1-μf capacity but the same amplifier may require a 25-μf condenser to by-pass a 200-ohm cathode resistor.

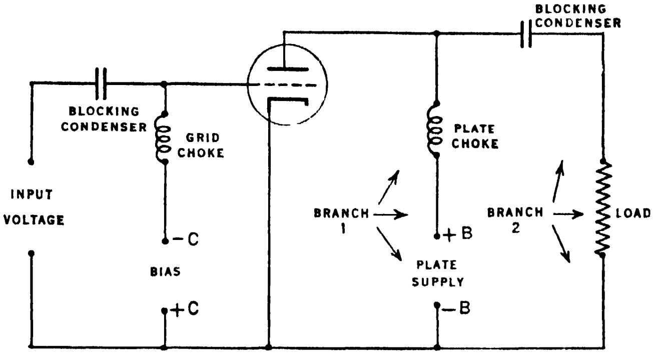

FIG. 5–2. Amplifier circuit with blocking condensers and choke coils to isolate the d-c and a-c circuits.

since these elements are to be kept free of a.c. they are bypassed to ground through condensers. The screen current (and to a lesser extent the suppressor current[3] is affected by the input signal. Without the by-pass condenser, this would produce an a-c screen voltage since the screen supply lead contains a resistance used to lower the d-c voltage to a value suitable for the screen. In radio-frequency applications, the inductance of the screen supply lead may be great enough to cause an a-c voltage drop, and for this reason it is advisable to place the by-pass condenser as close to the tube socket as possible.

Much simpler than the parallel feed circuits of Figures 5–2 and 5–3 are the equally common series feed circuits in which the plate choke is not required and is replaced by the load. Even parallel feed circuits frequently dispense with chokes, using resistors instead. Nor need the load be a resistor; it may be any power-consuming device or a transformer feeding such a device.

5–1b. Amplifier Classes—Amplifiers may be operated with various combinations of grid bias, input voltage, and plate voltage, each combination being especially suited for some particular purpose.

The alphabetical designations A, AB, B, and C have been applied to the four most important classifications. In addition, a suffix (1 or 2) is often added to the letter or letters to describe further the conditions of operation. The suffix 1 indicates that grid current does not flow at any time during the cycle of signal voltage, whereas the suffix 2 indicates that grid current does flow at some portion of the cycle.

In a Class A amplifier the grid bias voltage and the a-c signal voltage are of such values that plate current flows at all times. If a push-pull arrangement is used, plate current flows in both tubes at all times.

In a Class B amplifier the grid bias voltage is of such a value that, with no a-c signal voltage, the plate current is approximately at the point of cutoff. When an a-c signal voltage is applied, plate current flows for about one-half of each cycle of the a-c signal voltage. If a push-pull arrangement is used, plate current flows in one tube during one-half of the cycle of signal voltage, and in the other tube during the other half of the cycle of signal voltage.

A Class AB amplifier is one in which the conditions of operation lie between those of Class A and Class B. During the cycle of signal voltage, plate current will flow during more than one-half of the cycle but less than the entire cycle.

In a Class C amplifier the grid bias voltage is of such a value that the tube is biased considerably beyond the point of plate-current cutoff. When an a-c signal voltage is applied, plate current flows for considerably less than one-half of each cycle of

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[3] The use of R_2 and a suppressor blocking condenser is not as common as the simpler practice of connecting the suppressor grid directly to the cathode, whose d-c (and a-c, if any) voltage it then assumes.

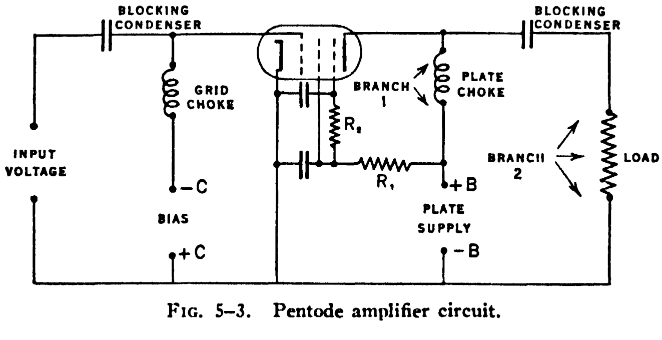


FIG. 5–3. Pentode amplifier circuit.

signal voltage. With a push-pull arrangement, plate current in each tube flows for considerably less than one-half of each cycle of signal voltage.

5-2. The Class A Amplifier—The Class A amplifier claims first attention because it is the simplest, oldest and most commonly used. Class A operation of tubes is found in all but a very few stages of the audio systems of radiotelephone stations, telephone systems, public address and motion picture sound systems, as well as in many less common applications. Class A is used in all the r-f stages, i-f stages and most audio stages of millions of radio receivers.

The plate-circuit efficiency of a Class A amplifier is 20 percent or less; hence the tube must be large if much power is to be handled without overheating. Fortunately most amplifier stages handle much less than one watt of power, so that they may operate in Class A, which has advantages possessed by no other class of operation.

In Class A amplifiers the grid bias is of such a value that plate current flows at all times even when there is no input signal. In Figure 5-4 is outlined the proper operation of a Class A tube. A conventional sine-wave signal is shown merely for illustration. Though the plate current contains both d.c. and a.c., it (as shown) never reaches zero and (what is not shown so clearly) the *average* plate current is very nearly the same as before the signal was applied. Thus a d-c plate-supply meter remains stationary. If the a-c signal voltage is too high, the plate current no longer remains fixed nor is the reproduction faithful; the amplifier is overloaded. An extreme case (conventionalized) is shown in Figure 5-5. The plate current meter would have risen considerably before this. As long as proper Class A operation continues, the invariable d-c plate current permits us to use a plate supply of simple construction, with little attention to regulation.

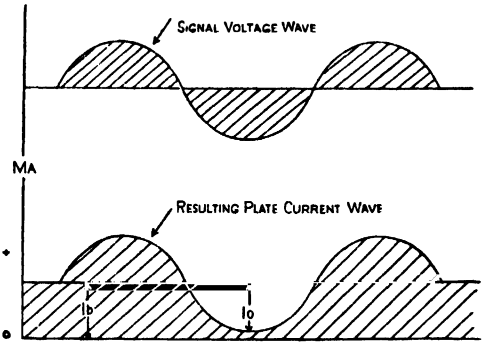


Fig. 5-4. The plate current of the Class A amplifier contains both d-c and a-c components.

5-2a. Grid Current—In a pure Class A amplifier the signal voltage is lower than the negative grid bias voltage. As long as this is the case, the grid is at all times negative with respect to the cathode and therefore no d-c grid current will flow. Inasmuch as there is no flow of grid current, the grid bias may be supplied through a high resistance, rather than a choke coil, as shown in Figure 5-6. This tends to make the amplification more uniform since the impedance of any choke varies with the frequency whereas the impedance of the resistor is substantially constant.

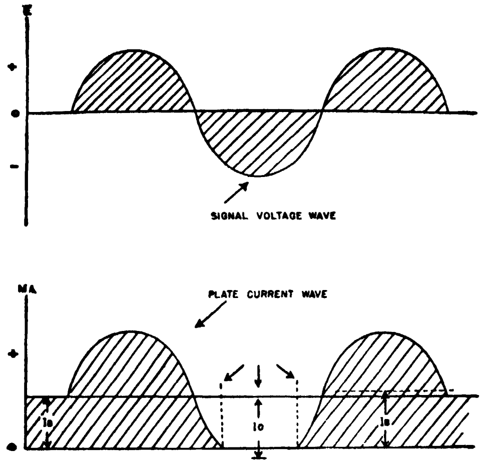


Fig. 5-5. Severe overload in Class A. When I_o (the a-c component) exceeds I_b (the d-c component) the plate current cannot reproduce the signal wave shape throughout the entire cycle. Distortion is introduced, and the amplifier is said to be overloaded.

The effect of these limits is shown by Figure 5-7 which shows the plate current, output current, plate voltage, output voltage, and signal voltage for a Class A amplifier. Each quantity is shown progressively for no output (1-2), half output (2-3), full output (3-4) and finally overloaded (4-5). For clarity this figure shows a triangular input wave form, not commonly encountered in practice.

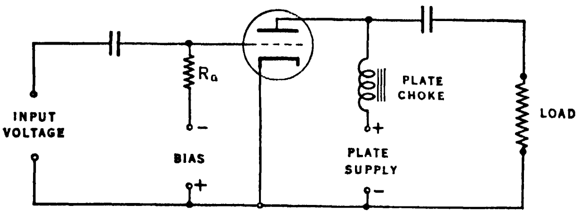


Fig. 5-6. Grid bias applied through grid resistor rather than grid choke as in Figure 5-2.

5-2b. Load Resistance—The load resistance presented to the tube determines the relation between the a-c plate current and the a-c plate voltage. When the load resistance is low, the plate voltage variations will be small. The power output will also be small. On the other extreme, if the load resistance is very high, the plate current changes will be so small (i.e., the a-c plate current is small) that the power output will be low, even if the plate

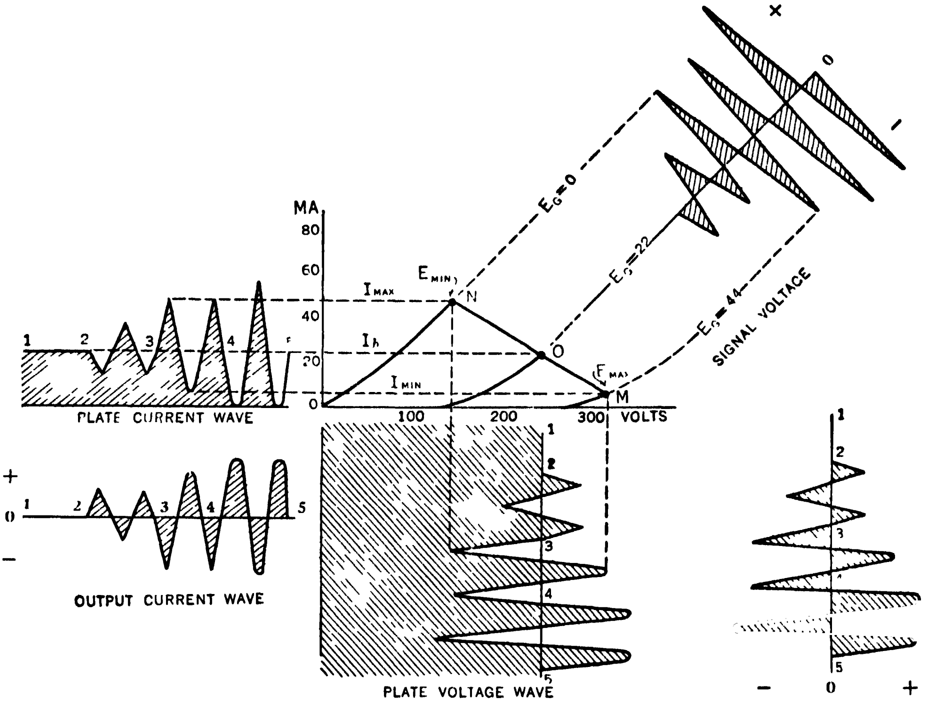


Fig. 5–7 Class A operation showing the relationship between signal voltage, plate current, plate voltage, and load resistance at various output levels

voltage changes are quite large It is evident that some intermediate value of load resistance will allow moderate variations of *both* plate current and plate voltage and consequently will permit the maximum power output. This value may be calculated by a process which is of little interest to the operator. However, the result is interesting. *Maximum undistorted output will (for triodes only) be obtained when the load resistance is equal to twice the internal plate resistance of the tube. Note especially that this rule applies only to triodes, also that it is not the rule for the greatest possible output.* If low distortion is not important a greater output may be obtained by using a load equal to the tube's plate resistance, that is, one half the value stated above. Only in Class A *audio* amplifiers is the "twice plate resistance" rule of consequence. For maximum *voltage* output, another rule obtains (see section 5–2g).

5–2c. Triode Power Output Computations— The application of the rule discussed above provides a simple graphical solution for triodes operated as Class A audio amplifiers. The values are worked out directly on the tube's characteristic curves.

Example:

Compute the audio power output of a type 6F6 pentode tube connected as a triode (i.e., grid No. 2 tied to the plate). The characteristic curves are given in Figure 5–8, and the maximum plate voltage is specified by the manufacturer as 250 volts.

Even when the screen is tied to the plate, a pentode is not a true triode. There is still the suppressor grid welded to the cathode though lying between screen and plate. However, it allows operation sufficiently like that of a true triode to permit use of the same methods, as follows:

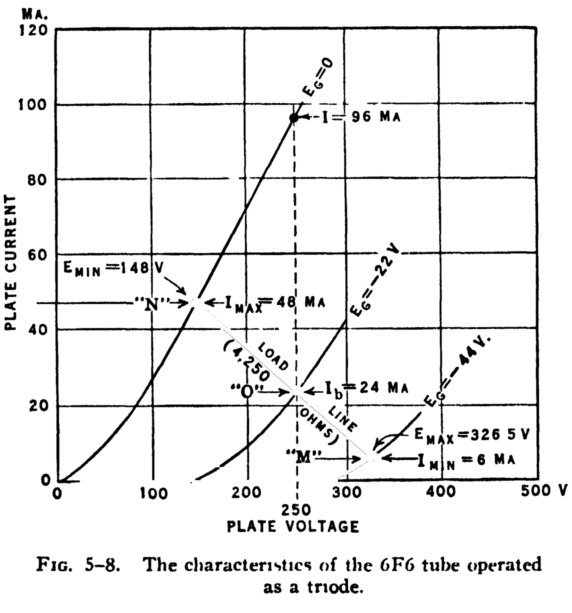


Fig. 5–8. The characteristics of the 6F6 tube operated as a triode.

1. Extend the zero grid voltage line until it intersects the applied plate voltage (250 volts). The plate current at the point of intersection is seen to be 96 ma. The operating plate current should be exactly one fourth of this current or 24 ma.

2. The desired operating plate current of 24 ma may be obtained by using a negative bias of 22 volts, as may be seen by examining the curves. The intersection of the grid bias voltage, the operating plate current, and the applied plate voltage is indicated as point O on Figure 5–8.

3. The upper end of the load line may now be picked off, by locating the point where the zero grid voltage line crosses a plate current of exactly twice the operating d-c plate current, in this case 48 ma. The plate voltage at this point, indicated as *N* on Figure 5–8 is seen to be 148 volts.

4. The load line is now drawn in, a straight line starting at point *N*, passing through point *O*, and ending where the grid voltage reaches twice the bias voltage or −44 volts. This end is indicated as *M* on Figure 5–8, and at this point the plate current is seen to be 6 ma, and the plate voltage is 326.5 volts.

5. The a-c output current is found by averaging the upward and downward swings of the plate current, or:

$$\text{peak } I_b \text{ a.c.} = \tfrac{1}{2}(I_b \text{ max} - I_b \text{ min}) = \tfrac{1}{2}(48 - 6) = 21 \text{ ma}$$

where I_b a.c. is the a-c component of the plate current, that is, the output current, I_b max is the current at *N*, I_b min is the current at *M*. In dealing with alternating currents, it is common practice to specify the rms values rather than the peak values (rms stands for "root of the mean square," which is a mathematical way of starting the *effective* value of a.c.—*which is the value indicated by any a-c meter*). Dividing the peak output current by the square root of 2, we obtain the rms output current:

$$I_b \text{ a.c.} = 21/1.414 = 14.8 \text{ ma}$$

6. The peak output voltage is found in similar manner by averaging the upward and downward swings of the plate voltage:

$$\begin{aligned}\text{peak } E_b \text{ a.c.} &= \tfrac{1}{2}(e_b \text{ max} - e_b \text{ min}) \\ &= \tfrac{1}{2}(326.5 - 148) = 89.2 \text{ volts}\end{aligned}$$

Converting this figure to the more common rms value:

$$E_b \text{ a.c.} = 89.2/1.414 = 63 \text{ volts}$$

7. The optimum values of output current and output voltage will be obtained only if the load resistance R_p is correct; that is:

$$R_p = E_b \text{ a.c.}/I_b \text{ a.c.} = 63/0.0148 = 4250 \text{ ohms}$$

In applying this equation, either peak or rms values may be used, but ***both*** figures must be expressed in the *same* units. Note also that the current is expressed in *amperes* instead of milliamperes. If milliamperes are used, the answer must be multiplied by 1000.

8. The power output may be found by multiplying the output current and output voltage:

$$\text{P.O.} = E \text{ a.c.} \times I \text{ a.c.} = 63 \times 0.0148 = 0.93 \text{ watt}$$

Here, again, the current must be expressed in amperes.

In solving for power output, steps 5, 6, and 8 may be combined to form the familiar equation:

$$\begin{aligned}\text{P.O.} &= (e_b \text{ max} - e_b \text{ min})(I_b \text{ max} - I_b \text{ min})/8 \\ &= (326.5 - 148)(0.048 - 0.006)/8 = 0.93 \text{ watt}\end{aligned}$$

The current is, of course, expressed in amperes.

5–2d. Distortion—In the example just cited, it will be noticed that the output current and voltage were not symmetrical. The upward swing of the plate current was from 24 to 48 ma, or 24 ma, while the downward swing was from 24 to 6, or only 18 ma. Likewise, the upward swing of the plate voltage was 250 to 326.5, or 76.5 volts, while the downward swing was 250 to 148, or 102 volts. These discrepancies are caused by the nonlinearity of the tube's characteristics.

If the resultant unsymmetrical output wave is analyzed, it will be found to contain harmonic components not present in the input voltage wave. The arithmetical sum of these harmonics, expressed as a percentage of the fundamental frequency, is the usual measure of the amount of distortion introduced. In a single tube Class A amplifier, such as the one just discussed, the distortion consists of a reduction, or flattening out, of every other half-cycle, i.e., the positive plate current swings are normal, but the negative plate current swings are all reduced. This type of distortion consists principally (not entirely) of *even* harmonics, of which the second harmonic (*twice* the input frequency) is the most important. The amount of this type of distortion may be estimated from the values already computed, thus:

$$\%\text{ distortion} = 100\,\frac{(2I_b - I_b \text{ max} - I_b \text{ min})}{2(I_b \text{ max} - I_b \text{ min})}$$

which for our example becomes:

$$100\,\frac{(2 \times 24) - 48 - 6}{2(48 - 6)} = 100\,\frac{-6}{84} = 7.15\%$$

The minus sign has no significance.

The most important feature regarding this distortion is that it can be reduced materially by a small reduction in the signal voltage, that is, by operating somewhat below the maximum capacity. Conversely any further increase in signal voltage will be attended by a rapid increase in distortion. The performance of a typical Class A amplifier is shown in Figure 5–9. Note that the operating level, selected for extremely low distortion, is considerably below the rated output which would be computed in the manner just described.

As it is obviously undesirable to operate high-power amplifiers far below their full output capabilities, good engineering practice is to accept about 2.5 percent distortion in the final amplifier. (The term "final amplifier" means the modulator in the case of a transmitter, or the stage that supplies the loud-speakers, in the case of a receiver or public address system.)

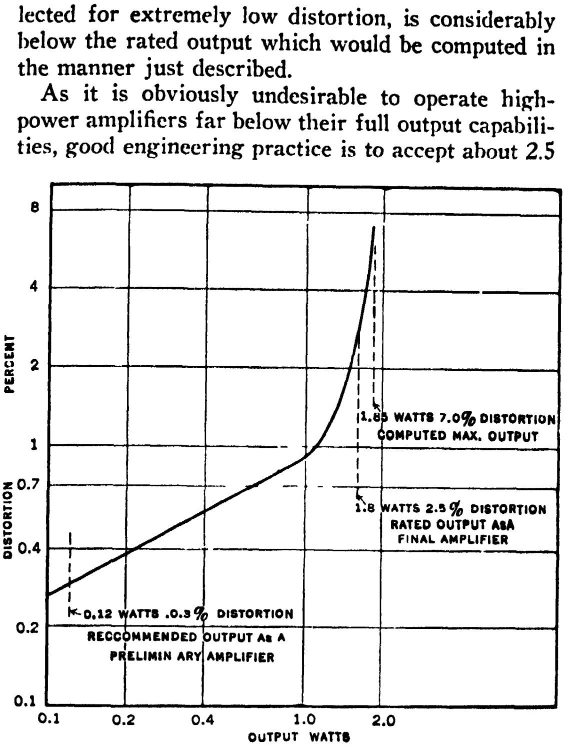


FIG. 5–9. Distortion characteristics of a Class A amplifier.

All low-level amplifiers should, however, be operated considerably below their full capacity in order to keep the overall distortion low. It is apparent that a series of, let us say, 8 stages, each operating so near its maximum capacity as to generate 2.5 percent harmonic distortion, would result in a combined distortion of an intolerable amount. Figure 5–9 shows the general relation between the computed output, the rated output as a modulator, and the recommended output as a preliminary amplifier.

5–2e. Push-Pull Class A Audio Amplifiers—The example just shown indicates that the performance of a single tube Class A amplifier is limited to a certain extent by the generation of even harmonics. These may be removed from the output by using two tubes in a push-pull circuit, one form of which is shown in Figure 5–10. The even harmonics of the individual tubes are in phase, whereas the fundamental output currents are 180° out of phase. By connecting to the load through a properly designed output transformer, the even harmonics will not be transferred. The principal distortion remaining is then the third harmonic (three times the input frequency). Unfortunately, tests have shown that a given percentage of third harmonic distortion is more objectionable to a listener than an equal percentage of second harmonic distortion. For this reason, a push-pull amplifier will not deliver appreciably more power than twice the single tube rating.

Push-pull Class A audio circuits do possess three very important advantages:

1. The d-c plate currents of the two tubes flow through the output transformer windings in opposite directions, thereby producing no steady magnetization of the transformer core. This is important, since the core need only be large enough to handle the magnetic flux caused by the a-c output current. This makes the unit more compact, less expensive and more efficient.

2. There is no tendency for the output current to flow through the power supply unless the tubes are unmatched. This greatly simplifies the by-passing and isolating necessary for stable operation. (A small degree of by-passing is usually provided to allow for lack of perfect balance between the two tubes.)

3. When the filaments are operated from a.c., the resulting hum is reduced by the push-pull action.

The student is cautioned not to confuse push-pull Class A amplifiers with Classes AB and B. Al-

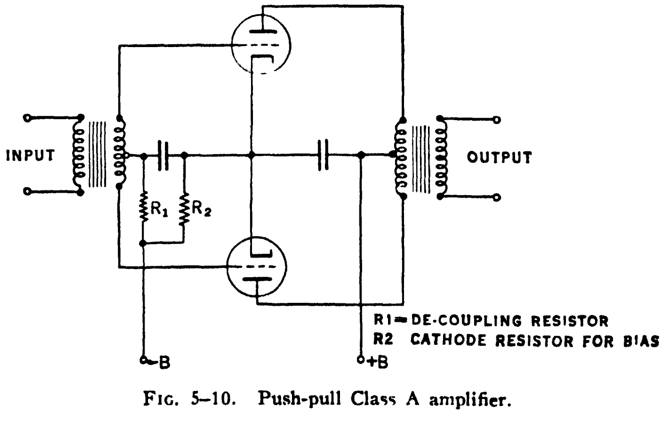


FIG. 5–10. Push-pull Class A amplifier.

though the circuits are essentially the same, the voltages and method of operation are different. In practice, it is easy to distinguish between them because Class A draws steady plate current at all times, whereas Classes AB and B plate current will swing with the signal.

5–2f. Class A Voltage Amplifiers—When an audio amplifier stage drives a loud-speaker, modulates an r-f stage, or feeds into a telephone line, the power output is an important consideration. However, if the amplifier load is of extremely high impedance, notably if the load is a succeeding Class A stage, then the tube's output power is small and the output voltage alone is of interest. We call such a stage a voltage amplifier. Most receiving tubes work as Class A voltage amplifiers; the r-f and i-f stages of receivers as well as the audio stages of most receivers are required to do no more than swing the grid of a following Class A stage.

5–2g. Factors Governing Voltage Amplification—The voltage amplification of a single tube (triode, tetrode, pentode or other type) is always something less than its mu (amplification factor). Thus if a 6C5 triode tube with an amplification factor of 20 is used, we shall never actually obtain a voltage gain of 20 times. A near approach is possible only if the frequency is *not* too high and the load resistance *is* high as compared to the internal plate resistance of the tube. This is not as easy as it sounds. The plate resistance of the general-purpose triodes such as the 6C5 are all in the order of 10,000 ohms, hence it seems that we need merely to obey the rule of section 5–2b, supplying a load of 2 × 10,000 or 20,000 ohms. This would in fact permit the greatest *undistorted power* output, which is perhaps a fraction of one watt for these small tubes, but the *voltage* amplification is not 20 by any means. It is:

$$\text{Voltage gain} \quad \text{amplification constant} \times \left(\frac{\text{load ohms}}{\text{plate ohms} + \text{load ohms}}\right)$$

which for the 6C5 tube is

$$20\left(\frac{20{,}000}{10{,}000 + 20{,}000}\right) = 14.6$$

In operation, this would mean that 4.8 volts of a.c. applied to the grid would produce about 70 volts output for driving the grid of the next stage. (Were it possible to make good the full mu of 20 we would need only 70/20 or 3.5 a-c input volts.) For a 3-stage amplifier this means that we need:

$$70/14.6/14.6/14.6 = .022 \text{ input volt}$$

It is now clear that for high voltage gain Class A amplification it is well worthwhile to use tubes with a high mu, *provided* it is possible to use loads of extremely high impedance. A high mu tube has higher plate impedance than the general purpose triode tubes just discussed, hence the high gain will not be realized unless the loads are rather extreme. As an alternative to high-mu tubes one may use the general-purpose tube already discussed and place between them devices which are capable of providing a voltage step-up. Such devices are invariably transformers with more turns of wire on the secondary than on the primary. High-fidelity transformers are invariably relatively expensive and have perhaps a 2/1 step-up. However, this step-up must not be underestimated for, if our 6C5 amplifier used only two such transformers, between the tubes, the required input would be dropped:

$$2 \times 2 = 4 \text{ times}$$

and the necessary input voltage would then become:

$$70/14.6/14.6/14.6/2/2 = .0055 \text{ volt} = 5.5 \text{ millivolts}$$

Combinations of general-purpose triodes and interstage transformers have been used extensively. The main objection to them in audio work is the cost and (for portable work) the weight of the transformers, and the tendency of the transformer to pick up hum from nearby power equipment. The cost objection will probably remain but recent transformer designs have greatly reduced the other two difficulties. It must be understood that the reference here has been to audio-frequency interstage step-up transformers. The kind of transformers intended to couple an amplifier output to a telephone line or with control equipment is not intended to provide a step-up, but rather to adjust impedances or to permit the use of a balanced-to-ground line with equipment which has one side grounded.

5–2h. Voltage Amplification with High-mu Tubes—When the voltage gain is to be increased by the use of high-mu tubes, it is first necessary to consider the available tubes. These consist of triodes with a mu around 75–100, tetrodes with a mu in the region of 500, and pentodes with a mu in the region of 1000 or more. All these types could be made with still higher mu, but it has already been pointed out that the full mu of a tube cannot be realized unless the load impedance is large compared with the plate-resistance of the tube. Thus it is quite profitless to double the mu unless one can also increase the load impedance. Triodes, tetrodes, and pentodes all are limited by this consideration.

In the case of the triode of receiving size, a mu of 100 produces a plate resistance in the neighborhood of 100,000, thus resulting in an actual gain of:

$$100\left(\frac{20{,}000}{100{,}000 + 20{,}000}\right) \quad 16.6$$

if the same 20,000 ohm load impedance is used as in the case of the general-purpose triodes of section 5–2g. This is not an impressive improvement over the gain of 14.6 obtained with the general-purpose tube having a mu of only 20. The difficulty is obviously that the output transformer has not a sufficient primary impedance to work effectively out of the high-mu tube. It is possible to make a transformer with more than 20,000 ohms primary impedance, even at low audio frequencies, but it is difficult to maintain good high frequency response at the same time; hence it is common practice to allow high-mu audio triodes to work into a resistance load instead of a transformer, for high resistances are inexpensive and do not favor any particular audio frequency. The circuit then resembles Figure 5–2 except that the plate choke is replaced by a resistor which is the real load, while the "load" of Figure 5–2 is now a gridleak of ½ to 2 megohms, the upper end of which connects to the grid of the following tube. The output voltage available across the load resistor now depends on the same rule which has already been used, but not all of that output voltage reaches the next grid, for the resistance-condenser combination (unlike a transformer) is a voltage divider and the available voltage is divided between (*a*) the blocking condenser and (*b*) the gridleak and tube following. It is therefore customary to make the blocking condenser large (0.1 μf or more for low audio frequencies), and to make the gridleak as large as possible without grid-blocking, say 1,000,000 ohms or more. This can be carried too far; a common difficulty with resistance-coupled amplifiers is severe distortion caused by reduction (or polarity reversal) of the grid bias due to leakage of plate voltage through the blocking condenser, whose leakage often becomes larger as the condenser is made larger. However, a reasonable and practical "made good" gain of 50 is possible for such a tube, with a plate-load resistor of 100,000 ohms and a plate-supply voltage of 250.

Intermediate between transformer coupling and resistance capacitance coupling is the type using a plate choke coil as shown in Figure 5–2, and commonly called impedance coupling. If the gridleak is also replaced by a choke, the combination is double impedance coupled. The performance is fairly obvious from what has been said. For audio work the chokes, of course, require iron cores to attain sufficient inductance at low frequencies, while at radio frequencies at least one of them is commonly condenser-tuned. The selectivity in this case is generally less than for an r-f transformer because of the closer coupling.

In Class A r-f amplifiers the triode is undesirable because of its tendency to oscillate whenever the frequency is high enough to permit appreciable energy to return to the grid through the tube's plate-to-grid capacitance. In fact the tube goes into oscillation long before the load has been made large enough to secure gains such as have just been discussed, and reasonable r-f voltage gain can be obtained from triodes only if they are neutralized. This is avoided by using the tetrode or pentode. The tetrode is not usually made with a mu exceeding 500, for its plate resistance then becomes so high that a proper load cannot be provided. The pentode's plate resistance is lower for the same value of mu, hence a higher mu is possible without running away from the load, and in practice r-f voltage gains about twice as great as for the tetrode are obtained.

5–2i. Audio-frequency Class A Output Circuits—Certain devices, including some headphones and magnetic speakers, are designed to present an acceptable impedance to Class A audio amplifiers. These devices may be connected directly in the plate circuit of a tube. In Figure 5–11a the headphones are connected between the plate supply and the plate of the tube. This simple connection has three objectionable features: (1) the plate current of the tube flows through the headphones and may, if the polarity is incorrect, reduce the permanent magnetism; (2) a shock may be received if the output device is not well insulated as all parts of the circuit are above ground potential; and (3) the d-c current flowing through the output device may burn out the windings. For these reasons, this connection is advisable only when the plate voltage is 90 volts or less, and the plate current not over 10 ma.

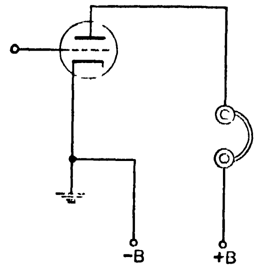


FIG. 5–11a. Simple connection of Class A amplifier. to headphones.

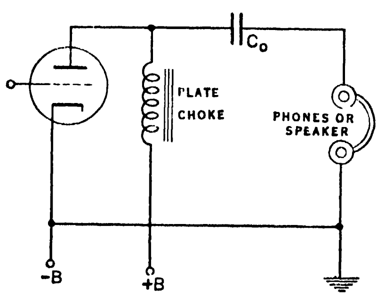


FIG. 5–11b. Showing how parallel feed may be used to prevent shock hazard present in circuit of Figure 5–11a.

In Figure 5–11b the d.c. flows through the plate choke. This presents a high impedance to the audio output currents. The output current therefore flows through the condenser C_0 into the speaker or phones. With this connection, one terminal of the speaker may be grounded, thereby eliminating the shock hazard. This circuit should be used in preference to the one shown in Figure 5–11 whenever possible.

The simple circuits of Figures 5–11 and 5–12 are not applicable to push-pull amplifiers. A transformer is necessary to connect the two tubes properly as shown in Figure 5–12. If the resistance of the load is correct for one tube, then for a push-pull stage the transformer must have a turns ratio of 1.41 to 1 from the entire primary to the secondary.

For each half of the primary to the secondary, the ratio will be 0.707 to 1. With two tubes, the total primary voltage can be seen to be double that computed for either tube. The primary current is as for one tube because the output current of each tube only flows through half of the winding. This makes the power delivered to the primary $2\ E_0\ I_0$, which is obviously correct. With a transformer ratio of 1.414′ to 1, the secondary voltage will be $2\ E_0/1.414'$ or $1.414\ E_0$; and the secondary current will be $1.414'\ I_0$. Dividing secondary voltage by secondary current, we find E_0/I_0 as the required resistance. As this is the speaker resistance we assumed, the transformer ratio is correct.

To avoid confusion from the similarity of the numbers, the figure 1.414 marked with a prime (′) represents the transformer ratio. Where the figure 1.414 is written without a prime, it is the result of an arithmetical operation.

When audio amplifiers deliver power to low impedance devices such as loud-speaker voice coils or telephone lines, proper coupling can be secured only by the use of a step-down transformer. The ratios required can be found by simple computations.

Example: A single-ended audio amplifier requires a load of 4250 ohms. What transformer ratio is necessary if the amplifier is to feed into a 500-ohm line?

Solution: The transformer ratio is equal to the square-root of the impedance ratio or:

$$\text{Primary turns/secondary turns} = \sqrt{\text{ohms wanted at tube/load ohms}} = \sqrt{4250/500} = 2.91$$

This formula is for single-ended Class A amplifiers only.

The required turns ratio is 2.91 to 1, the primary having the greater number of turns.

Example: Two tubes operated in Class A push-pull are to be coupled to a 15-ohm voice coil. The proper load for either tube has been found to be 4250 ohms.

Solution: In the case of push-pull Class A amplifiers, the plate-to-plate load impedance should be twice the required load for either tube. This figure may be used to obtain the ratio of entire primary to secondary. Thus:

$$\text{Primary turns/secondary turns} = \sqrt{2 \times 4250/15} = 23.8$$

This formula is for Class A push-pull amplifiers only.

The required ratio is 23.8 to 1 for the entire primary to the secondary.

5–2j. The Cathode Follower—*Cathode follower* is the name given to an electron tube stage when the load is in the cathode instead of in the plate circuit. This type of circuit has several distinct and meritorious applications. The circuit arrangement for triodes and pentodes is shown in Figure 5–13. The pentode cathode follower stage is used in preference to the triode in applications where a lower input capacity or a higher output voltage is desired. The effective internal impedance of the tube is the reciprocal of the grid-to-plate transconductance in mhos and must be added in parallel to the cathode resistor to determine the output impedance Z of Figure 5–13.

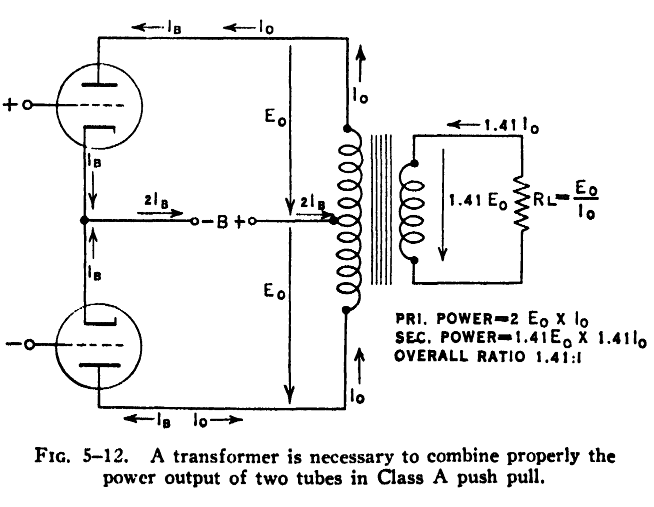
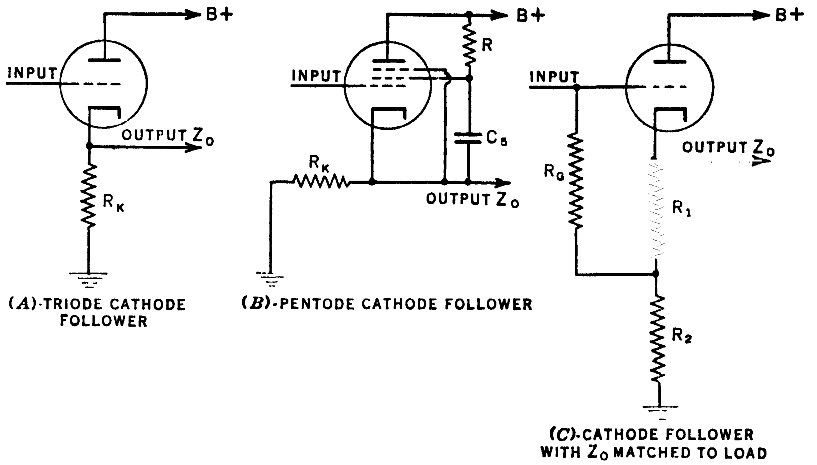


FIG. 5–12. A transformer is necessary to combine properly the power output of two tubes in Class A push pull.



(*A*)-TRIODE CATHODE FOLLOWER

(*B*)-PENTODE CATHODE FOLLOWER

(*C*)-CATHODE FOLLOWER WITH Z_0 MATCHED TO LOAD

FIG. 5–13. Cathode follower circuits.

The stage gain is given by:

$$A = \frac{G_m R_k}{1 + G_m R_k}$$

Thus it can be seen that the stage always operates with a gain of less than 1 and that the higher the value of R_k, the closer to unity the gain becomes. The arrangement of Figure 5–13c is sometimes used to secure higher output voltages. In this circuit R_k is divided into two parts, and R_1 and R_2 are arranged so that the d-c voltage across R_1 is equal to the required grid bias; as the grid is returned to the junction of R_1 and R_2, the correct bias will be obtained. The G_m will not change, but R_k will be increased and thus also the voltage output. Similarly, Z_0 will be changed.

Cathode followers are used extensively in video work as an impedance changing device. For example, the output voltage of an amplifier taken from the plate circuit is of comparatively high impedance, and the problem of designing a transformer to reduce the impedance to that of a transmission line through a range of video frequencies from 30 cycles to 5 mc with a uniform frequency response is difficult, although easily solved by use of a cathode follower stage.

Other applications include:

(*a*) To serve as a driver for a Class B audio amplifier, thus eliminating an input transformer.
(*b*) As a substitute for a plate-to-line transformer for a microphone preamplifier.
(*c*) To provide a voltage range control for the input of a high-gain amplifier.

In fact, whenever a circuit which has a low internal impedance is required, or when there is a need to connect to a circuit without loading it, the cathode follower can be used to advantage. However, it must be kept in mind that, as shown previously, the cathode follower stage provides less than unity amplification and therefore introduces a loss instead of a gain. However, in the final analysis, the overall advantages often more than compensate for this slight loss of amplification.

5–2k. Class AB Audio Amplifiers—As the designation indicates, the AB class lies between Class B and Class A. It may be regarded as an overbiased and overswung Class A stage, for at low levels the plate current flows throughout the cycle, and even the highest operating level does not reduce it to mere half-cycle pulses. On the other hand it may be regarded as an underbiased Class B stage and, like the true Class B stage, requires actual power input to the grid, except at low audio levels, hence the driver conditions resemble those of Class B for a part of the cycle.

The merit of Class AB is that it avoids the low-level distortion of Class B by operating in approximate Class A for this region. At high levels the operation is substantially Class B, with consequent high efficiency and output. It might be thought that distortion would be encountered but in practice very satisfactory results are possible.

Class AB is divided into Class AB_1 (no grid current at any time) and Class AB_2 (drawing grid current at the upper part of its range) but this is a distinction of degree rather than basic difference.

5–3. Class B Amplifiers—Class B operation will enable an audio push-pull stage to deliver about 5 times the power output that could be obtained from the same size of tubes in Class A. It follows that Class B operation becomes interesting whenever the power level is such that the tube cost has risen considerably. Likewise the higher plate-circuit efficiency of the Class B stage effects a power saving which may in itself be a consideration if the output is to be anything above perhaps 100 watts. Finally, it is clear that a change from Class A to smaller tubes in Class B may sometimes permit a lower plate voltage supply system. It is not necessarily true that Class B is always cheaper than Class A. In both transmitters and receivers, cases are common where no saving in the plate supply system results since the rest of the system must be supplied as before. It is even possible to find cases where the Class A system operates satisfactorily from a certain source, while a Class B system, because of its fluctuating plate current, disturbs that supply and requires additional filtering or an independent supply. An additional driver audio stage may be necessary to provide the grid power demanded by the Class B stage. General statements are unwise and each case should be studied. That is not within the scope of this chapter, and we now turn to the operation of the Class B amplifier.

The increased efficiency of the Class B stage, as compared to Class A, is due in part to the elimination of most of the plate input when the tube is resting, which is accomplished by the high negative grid bias of cutoff value, or by the use of a special tube with a fine-mesh grid which requires no bias for Class B operation. Thus plate current flows only when the grid is swung by the signal input, and flows in more or less direct proportion to this excitation. The output of the tube will not be of the same form as the grid input but is an amplified *and rectified*, or half-wave, copy of the a-c grid input, because the tube can produce output on the positive grid swings, but on the negative swings it can do nothing for it is already cut off, and a further negative swing produces no effect. Thus one definition of a Class B stage is:

"An amplifier in which the grid bias is approximately equal to the cutoff value so that the plate current is approximately zero when no signal voltage is applied, and the plate current . . . flows during approximately ½ of each cycle when a signal voltage *is* applied."

It is not essential that two tubes be used unless fidelity of reproduction is necessary. A single Class B tube is quite capable of driving a tuned circuit or delivering power to a variety of devices, and this may be done at either audio or radio frequencies. The radio-frequency use of a single-tube Class B amplifier is the more common as it is possible to use the flywheel effect of the tuned circuit to fill in the missing half-cycles and thus produce an alternating or full-wave current. *In audio Class B work it is true that two tubes (in push-pull) are necessary.*

5-3a. Audio-frequency Class B Push-pull Amplifier—Figure 5-14 shows the wave forms (but not relative amplitudes) of the grid and plate circuits in a very highly idealized Class B amplifier and attempts to explain how the two half-wave outputs are combined by an output transformer into a full-wave output. In an actual Class B stage the conditions are not as ideal, for the two half-wave outputs do not join so precisely end-to-end, even when the optimum value of grid bias is used. The discontinuity is minimized by proper transformers. Another departure from ideal conditions arises from the fact that the Class B grid draws a varying grid current as it swings more or less deeply into the positive-grid region. Thus the grid becomes a varying load upon the driver stage, and serious distortion is possible unless the driver stage is one capable of tolerating such varying loads. This is a requirement most simply met by a large Class A driver stage of low amplification constant, coupled into the Class B grids by means of a step-down transformer. If the driver is not adequate there will be rapidly increasing distortion as the point of increasing Class B grid current is reached.

5-3b. Class B Audio Amplifier Plate Efficiency—It is quite outside the scope of this book to present the mathematics of Class B audio design in full, but an outline may be useful. It will be recalled that Class A amplifiers draw a continuous plate current when idle, and that as the signal is applied and is increased, a larger and larger part of this input is converted into output, so that the plate efficiency gradually rises from 0 to about 20 percent. In Class B amplifiers a similar rise of efficiency with signal input takes place, but the absence of a large resting plate current makes it appear reasonable that there be greater efficiency, especially as the Class B tube operates with larger a-c grid voltages, made possible by a driver adequate for swinging the grid into the positive region. Thus the full-load efficiency is in the region of 60-66 percent in familiar tubes.

A limitation to Class B operation, which is not readily apparent to the user not equipped with suitable measuring equipment, is that a tube of a type which does not show overloading by visible plate-heating may cause the operator to be misled into thinking that increased operating level is justified when actually the peaks of the plate-current wave are being clipped off through one of two possible effects. One of these is driving the grid so highly positive that overheating of the grid and distorting of the plate current wave form results. Further distortion is introduced by the abrupt change in driver load due to the sudden rise in Class B grid current, also by the probability of dynatron oscillations in the Class B tubes. These limitations are more severe in large water-cooled tubes where grid heating more surely results in tube failure. The manufacturer's ratings should be observed in all Class B work unless the full effect of changes is clearly understood. There is one exception to this warning: In uses where the tube life will ordinarily terminate by leakage or accident, rather than through filament wear, it is economically justifiable to hasten the filament wear by overrunning a tube for the purpose of securing larger output and thus avoiding the purchase of a larger tube. Thus a radio amateur may find it economical to over-run

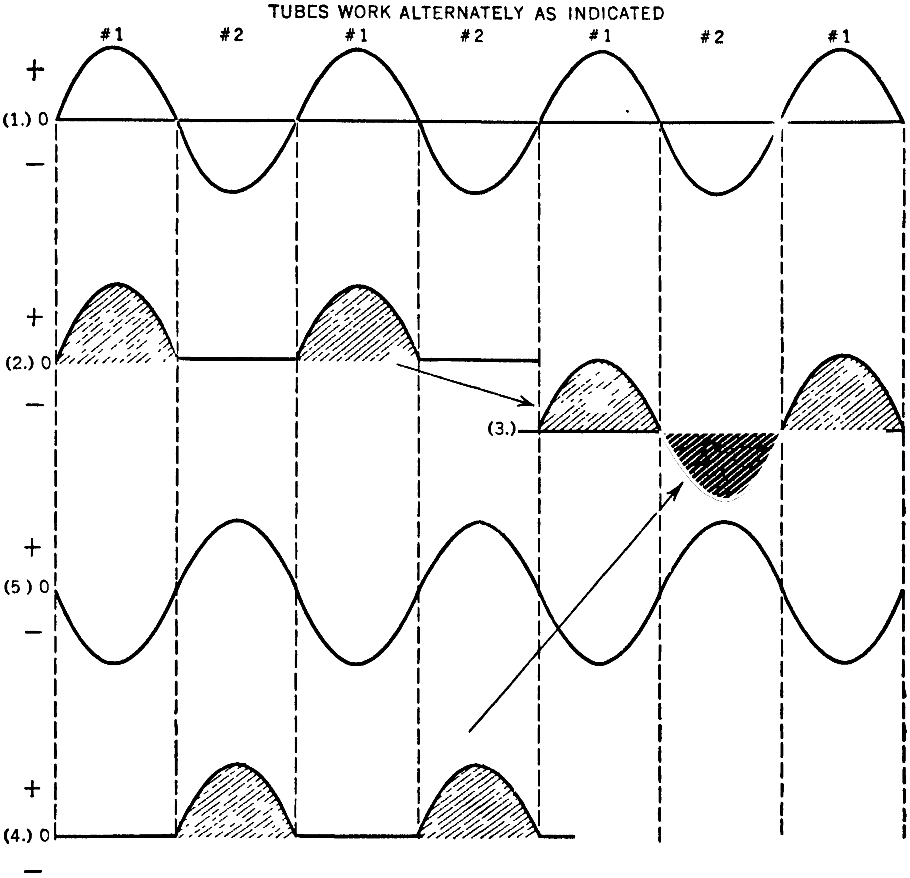


FIG. 5–14. Plate current flow in Class B audio amplifier.
1. Signal voltage on grid of Tube 1.
2. Plate current of Tube 1.
3. Output current, Tubes 1 and 2 combined by output transformer.
4. Plate current of Tube 2.
5. Signal voltage on grid of Tube 2.

a pair of tubes with a Class B audio rating of 45 watts and a cost of $7, rather than to under-run a pair rated at 110 watts and costing $20—simply because he intends to use the equipment perhaps 200 hours per year. The same practice applied to commercial service, 12 hours per day, 365 days per year would be costly even if the increased frequency of service failures is not taken into account.

Nevertheless the fact remains that the peak values of plate current in Class B stages are higher than any reading of the direct-current meter in the plate supply line by a factor in the vicinity of 1.56/1, and the possibility of swinging into the saturation region is an actual one when maker's ratings are exceeded. In fact, as the emission decreases with tube aging, this eventually takes place at normal rating and unsatisfactory or unbalanced operation of a Class B stage may be due to an emission failure of an aging tube.

5–3c. Driver Stages for Class B Audio Amplifiers—As already indicated, the d-c grid current of a Class B stage depends upon the characteristics of the tube and upon the instantaneous grid and plate voltages. During each cycle, as the grid swings toward the positive, the plate voltage naturally falls because of the a-c voltage drop in the tube's load. The grid current does not rise uniformly, but slowly at first and then more rapidly. At about the point where the grid voltage has risen to ½ of the instantaneous plate voltage the grid current begins to rise rapidly. At this point the a-c grid driving power is about 5 percent of the output power. As this is not an unreasonable power it is frequently used for design.

The fact that there is d-c grid current in the Class B stage necessarily compels the preceding or driver stage to supply actual power rather than mere voltage, as in the Class A stage. In consequence, the performance of the Class B stage is so closely associated with the driving stage that the two must be designed together. The driver is usually a Class A power amplifier stage, that is, a stage using low-mu tubes, but unlike some other cases this stage must work into a load which varies. It will be recalled that the gain of a Class A stage is equal to the product of load resistance and amplification constant, divided by the sum of the load resistance and internal plate resistance. As the load-resistance becomes smaller, the amplification is reduced. The reasonableness of this is apparent when one considers that this process would end in a short circuit, which naturally permits no amplification. If the load resistance equals twice the Class A tube's plate resistance, the equation will show the amplification to be equal to mu (2/3). Thus, a swing from an extremely high-resistance load to a load equaling twice the Class A tube's plate resistance would be a 33 percent change in voltage gain and cause serious distortion of the signals. While the range of loads stated is not intended to represent any practical case, it illustrates the desirability of preventing load-excursions and explains why tube data commonly recommend that a Class A tube be given a high resistance load when driving Class B grids, this being accomplished by means of a transformer whose primary turns are more numerous (usually) than their secondary turns. A proper loading condition is arrived at somewhat automatically if the driver tubes have a normal Class A rating at least 4 times the required driving power, and if the input transformer of the Class B stage is so designed that the Class B grids will just receive their full voltage swing when the driver tubes are operating at full output. If this is to be done from voltage-ratio considerations, the peak a-c voltage in the Class A plate circuits and the required peak grid swing of the Class B circuits provide the starting point, while the power to be handled, the lowest frequency wanted, and the need of keeping the secondary resistance down to perhaps 1000 ohms for a small Class B tube indicate the size of the transformer.

5-3d. Class B Amplifier Performance—Figure 5-15 shows the distortion characteristics of a typical low-grade Class B amplifier stage. At low grid swings the grid operates in a region where it is just beginning to collect grid current; therefore the tube's characteristics are changing rapidly and the distortion is high. This tendency is characteristic of all Class B amplifiers. In this case the curve starts off at 3 percent and almost immediately rises to 5 percent. However as the grid swing is extended it reaches into the more linear region and the better performance in that region begins to average down the higher distortion in the lower part of the swing so that a minimum of 2 percent is reached. However as the grid current continues to rise and presently enters the region of increasingly rapid rise, the load on the driver changes and with it the distortion, which once more goes up to 5 percent. The difficulty in this case is not altogether in the Class B stage, but resides partly in the use of a driver not adequate for the work, and therefore too greatly affected by the changing load. Thus, it has already begun to give bad performance at the time the useful power limit is reached. Figure 5-16 shows the performance of a high-grade Class B audio stage with a proper driver stage, and with tubes specifically designed for Class B use.

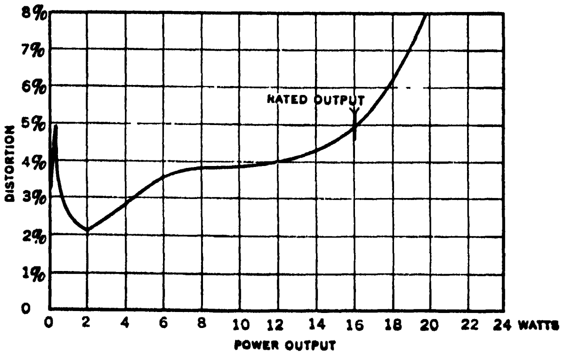


Fig. 5-15. Distortion characteristics of low-grade Class B audio stage.

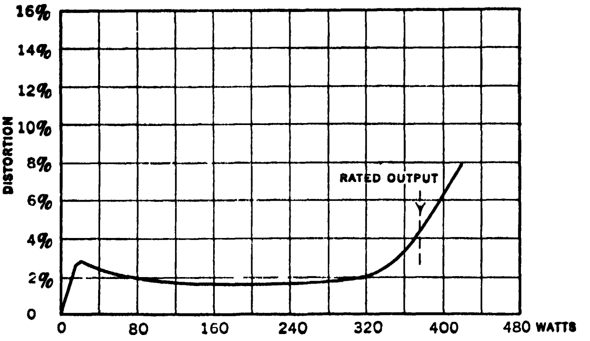


Fig. 5-16. Distortion characteristics of high-grade Class B audio stage.

5-3e. Special Class B Tubes—Several varieties of tubes have been introduced particularly for Class B audio service, though most of them are also useful in other ways. One of these tubes consists of two small high-mu triodes built into a single envelope for use in the audio output stage of receivers. This has the merit of compactness. These dual tubes may be, and often are, of the very high-mu varieties which are nearly self-cutoff and require no bias voltage. Such zero bias tubes are also available in individual envelopes and are made in all sizes including a 100-kw water-cooled variety. There are also two-grid tubes which become high-mu zero-bias Class B tubes when the grids are tied together, but become moderate-mu Class A driver tubes when one grid is tied instead to the plate. Finally there is the variable-mu type of triode, more or less overlapping some of the varieties already mentioned, and possessing advantages as regards ease of drive and improved performance.

The curve of Figure 5–16 was obtained from such a pair of tubes.

5–3f. Power Limit of Class B Audio Tubes—In designing Class B audio amplifiers, there are four factors that limit the power obtainable from a given pair of tubes:

1. The safe plate voltage must not be exceeded.
2. The peak plate current must not exceed the emission capability of the cathode.
3. The power dissipated at the plate must not be excessive.
4. The audio driving stage must not be overloaded.

The first item depends upon the internal construction of the tube, particularly upon the spacing of the supports and leads in the "press" where the wires pass through the glass. The plate voltage limit must be specified by the manufacturer because it cannot be determined by test without risking destruction of the tube.

In small tubes, such as those designed for receivers, the filament emission is limited (to save filament power) and item 2 is an important limit. For this reason, a plate current limit is usually specified by the manufacturer. Exceeding this current will result in loss of emission. On the other hand, the size of the plate and the envelope are adequate so that (except at unusually high plate voltages) the plate dissipation is not a limit. With larger tubes, the reverse is true. Filament economy is of minor importance so an abundance of emission is available, especially if the tube is also intended for r-f service. For such tubes the size of the plate and envelope are the principal limit. The power that can be safely dissipated is always stated by the manufacturer.

5–3g. Class B Audio Computations—Given two tubes with the characteristics shown in Figure 5–17; safe plate voltage 400; and dynamic peak plate current limit 200 ma per tube; solve for:

1. Grid bias.
2. Signal voltage.
3. Output voltage.
4. Output current.
5. Power output.
6. Plate input.
7. Plate efficiency and plate dissipation.

Solution—First Method—1. Examination of the characteristic curves shows that at the operating plate voltage the plate current is nearly cutoff with zero grid voltage. Negative bias is, therefore, unnecessary.

2. On the characteristic curve, mark off each point where the plate voltage is just twice the grid voltage. Draw a line through these points. This is the nearly vertical broken line marked $2E_G = E_P$. Any point on this line, or to the right of the line, satisfies the arbitrary requirement given in section 5–3c for reasonable driving power. This line crosses the specified plate current limit (200 ma) at a grid voltage of 60 and a plate voltage of 120. These are, respectively, the maximum positive grid voltage and the minimum instantaneous plate voltage. With zero bias, it is evident that the signal voltage for full output must be 60 volts to attain the required maximum positive grid voltage. This is a peak value, the rms value being 0.707 × 60, or 42 volts.

3. The peak output voltage is the difference between the applied plate voltage (400) and the minimum instantaneous plate voltage (120), or 280 volts. The rms voltage is 0.707 × 280, or 198 volts.

4. The peak output current is equal to the dynamic peak plate current already specified as 200 ma.

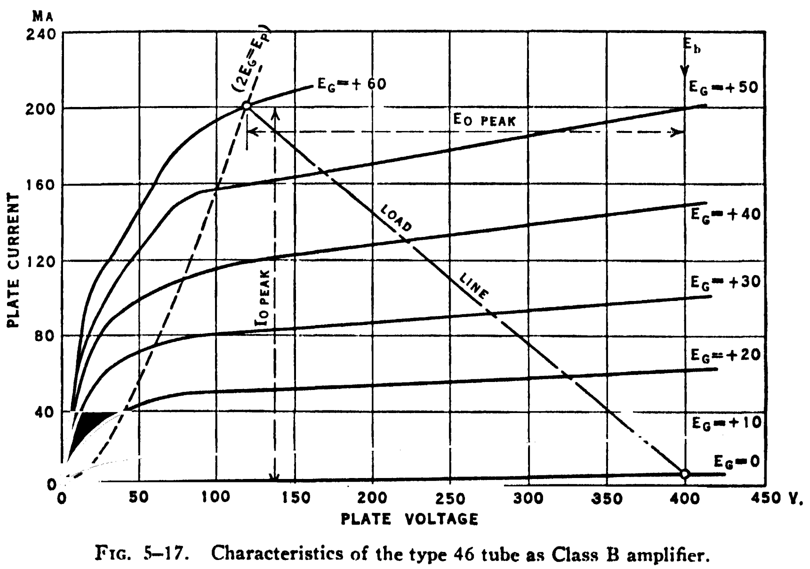


Fig. 5–17. Characteristics of the type 46 tube as Class B amplifier.

The rms current is 0.707 × 200 ma, or 141 ma (0.141 ampere).

5. The product of rms output voltage and current is the power output, or: $P_{out} = 198 \times 0.141 = 29$ watts.

Note—This is the tube output. From it must be deducted the losses in the output transformer to obtain the actual power at the secondary. For such low powers, transformer efficiencies run about 75 percent, making the net output power 21.6 watts.

6. The average plate current of either tube is 0.318 times the dynamic peak plate current. This factor is an inherent characteristic of the Class B plate current wave shape. In this case, the average plate current is 0.318 × 200 ma, or 63 ma per tube, or 126 ma for both tubes. This is, of course, obtained only at full output.

7. The plate input is the product of average plate current and plate voltage; that is: $P_{in} = 400 \times 0.126 = 50.4$ watts. Deducting the tube output of 29 watts, we obtain the plate dissipation; that is, $50.4 - 29 = 21.4$ watts. This is, of course, shared between two tubes, so that either tube must dissipate half this amount or 10.7 watts loss per tube. The plate efficiency is the tube output divided by the input, which is $29/50.4 = 0.576$, or 57.6 percent plate efficiency.

In the example just given, the plate dissipation of either tube was shown to be 10.7 watts. The manufacturer's limit is 10 watts. If adequate ventilation is provided, this slight excess will do no harm. However, if conditions are unfavorable, it may be desirable to operate the amplifier at a reduced output level.

Solution—Second Method—Experience with typical tubes has shown that a plate efficiency in the order of 60 percent is obtained at full output. Thus, the full output (60 percent of the d-c input) is just 1.5 times as large as the plate dissipation (the remaining 40 percent of the d-c input). The power output of any two tubes in Class B audio can be quickly estimated by multiplying the rated plate dissipation (for both tubes together) by the factor 1.5. However this leaves no margin at the maximum loss level which is slightly below the full output point and a more correct value is 1.44. It must be understood that this factor is an estimate, based upon a probable plate efficiency of 60 percent at full output. The actual output may differ somewhat. It is, however, useful in making a solution when the plate dissipation (rather than the plate current) is the limiting factor. This will be illustrated by an example.

Example: Given a pair of tubes with safe plate dissipation limit of 35 watts each, plate voltage 1250, and characteristic curves as shown on Figure 5–18. Operated as a Class B audio amplifier, solve for:

1. Grid bias.
2. Plate input for full output.
3. Signal voltage for full output.
4. Computed power output.
5. Plate efficiency, and plate dissipation at full output.

Solution: From inspection of the curves of Figure 5–18 it may be seen that, neglecting the curvature at its lower end, the plate-current curve for a grid voltage of −70 reaches zero current at 1250 volts, which is to say −70 volts is the cutoff bias for this tube at a plate voltage of 1250. This is the required bias for Class B operation. Using the factor of 1.44 already mentioned, the estimated power output for a plate dissipation of 70 watts (35 per tube) is 1.44 × 70, or 101 watts. It might be reasoned that the full load input is to be 70 loss-

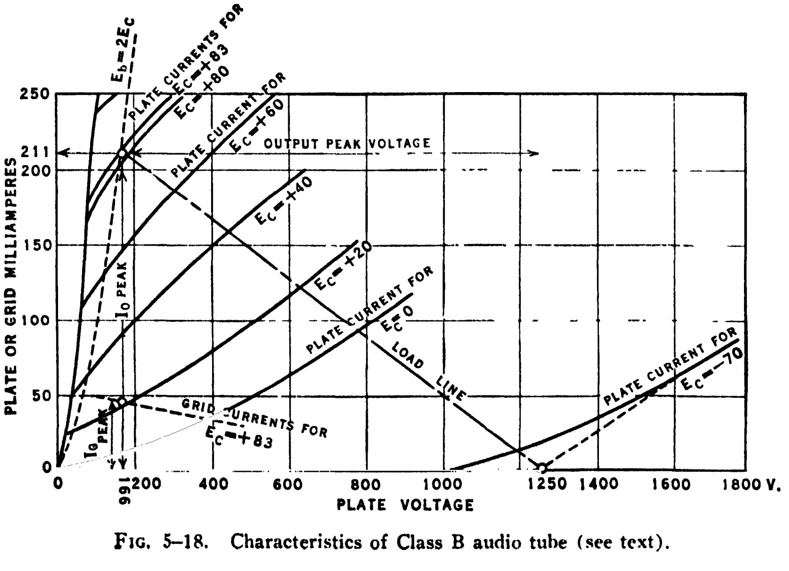


FIG. 5–18. Characteristics of Class B audio tube (see text).

watts + 101 output watts or 171 watts, but this is not altogether correct for the full load loss is less than the loss at a slightly lower level. At full load we again assume 60 percent efficiency and the required input is seen to be $\frac{144 \times 70}{0.6} = 168$ watts plate input to both tubes at full load. At 1250 volts, 168 watts is represented by 168/1250, or 0.134 amp. This, of course, is for both tubes. For either tube it is half of this, or 0.067 amp. With the shape of current wave met in Class B plate circuits the peak plate current is related to the average by the factor 3.14, that is, the peak current is 3.14 × 0.067, or 0.211 amp. This is the dynamic peak plate current of one tube at full output.

Turning again to Figure 5–18 and the line labeled $E_b = 2E_c$, this line, at the point of maximum dynamic plate current just found (211 ma), is slightly above the plate-current curve for a grid voltage of + 80 at about + 83 volts. Accordingly a curve for + 83 volts has been drawn in and the point where it crosses the $E_b = 2E_c$ line is labeled *O* for convenient reference. Ignoring all curves for a moment, it is seen that *O* is at a height of 211 ma (vertical scale at left of figure), while it is 166 volts to the right of zero (horizontal scale at the bottom of the figure). These values are respectively the maximum peak plate current and the simultaneous minimum peak plate voltage, while the + 83 line through *O* represents the grid voltage at that same peak instant. The synchronous occurrence of + 83 at the grid, and + 166 at the plate, is as it should be, for it was originally determined that the plate voltage at this peak was to be twice the grid voltage and 166 equals 2 × 83.

To proceed: Since the grid is to be swung to + 83 despite a d-c bias of − 70 volts it is clear that the audio a-c grid input peak voltage must be 70 + 83, or 153 audio peak volts. This corresponds to an rms value of 0.707 × 153, or 108 rms grid input volts. In the plate circuit it is clear that the minimum voltage of 166 is due to the a-c peak which must accordingly be within 166 volts of the plate supply voltage, that is, 1250 − 166, or 1084 peak a-c plate volts, or 766 rms a-c plate volts.

The peak plate current has already been found, being 211 ma, which is 0.707 × 211, or 0.149 rms amp, or 149 rms ma. Thus the power output is 0.149 amp × 766 volts = 114 watts, but not all of this reaches the actual load as some is lost in the output transformer. Assuming the transformer to have an efficiency of 90 percent, we find the useful output to be 114 × 0.9, or 102.5 watts useful output from the transformer secondary.

5–3h. Class B Output Transformer Efficiency—There is no inherent connection between power rating and efficiency, but economic factors, including the cost of labor, material and power, control the actual quality of commercial transformers roughly as follows: The figures relate to Class B output transformers only:

Up to 25 watts	75 percent
25–100 watts	85 percent
100–500 watts	90 percent
500–5000 watts	95 percent
over 5000 watts	98 percent

Returning to the Class B stage proper, the plate efficiency is determined by dividing the tube output by the plate input as in the previous cases, that is, 114 watts tube output divided by 168 watts input = 67.9 percent plate efficiency. The plate loss is clearly the difference between input and output, that is, 168 − 114 = 54 plate loss watts or 27 watts per tube.

It has been stated that the maximum loss does not take place at full load. In this case it takes place when the signal input voltage is 79.5 rms volts and amounts to 30.8 watts, nearly 4 watts per tube more than at full output.

The load impedance required to obtain the above conditions is obviously equal to the output voltage divided by the output current, that is, 766 output volts/0.149 output amp, or 5140 load ohms.

As only one tube is active at any instant, this is the effective impedance that must be presented by either half of the output transformer primary. The plate-to-plate impedance offered by the whole primary winding will be four times this value, or 20,560 ohms. This value is convenient when computing transformer ratios which are normally specified in terms of entire primary to secondary.

5–3i. Predicting Driving Power—The driving power required by the Class B stage is equal to one-half the product of the peak grid current and the peak signal voltage. In the above example the peak grid current is 0.045 amp (from the curves for a grid voltage of + 83 and a plate voltage of 166) and the peak signal voltage is 153 volts (sum of 70 volts grid bias and 83 volts peak signal swing). This makes the required driving power 3.44 watts. The driver should be capable of four times this power, or 13.7 watts, with low distortion. This can be conveniently obtained from push-pull low-mu triodes, preferably with fixed bias.

5–3j. Audio-frequency Class B Output Circuits—Class B push-pull output transformers differ from Class A push-pull output transformers in that only half of the output transformer primary is active at any instant because the two tubes work on alternate half-cycles. The ratio is figured on the basis of half of the primary and the load resistance of one tube.

Example: A certain tube in Class B audio application requires a load of 5140 ohms. What output transformer ratio is necessary if the actual load is a Class C amplifier operating at 1000 volts and 0.1 amp?

Solution: The impedance which the Class C stage will present to the secondary of the output transformer is found by dividing the Class C amplifier plate voltage by its plate current, that is, 1000/0.1 = 10,000 ohms.

The transformer turns ratio between either half of the primary and the secondary can now be found:

$$\text{Turns } \tfrac{1}{2} \text{ primary/secondary} = \sqrt{\text{desired tube load/load resistance}} = \sqrt{5140/10{,}000} = 0.716$$

This formula applies for Class B output circuits only.

The required turns ratio is 0.716 to 1, for half the primary to the total secondary. However, the ratio of the entire primary to the secondary is twice this, or 1.43 to 1.

5–3k. R-f Class B Operation—In radio-frequency amplification there are two distinct and separate fields. One is the extremely low power level amplification of received signals, which can be accomplished most satisfactorily by the Class A r-f amplifier as previously discussed, even with the smallest of tubes. The other field is that of the transmitter in which the power to be handled is not measured in microwatts and milliwatts but in watts and kilowatts, so that tube efficiency becomes of importance and Class A amplification loses its attractiveness, at least to some extent, and Classes B and C become attractive as the power level rises. *Most of the amplifiers in radio transmitters operate in Class C.* The reason for this is that a Class C stage provides higher efficiency than a Class B stage and, consequently, higher output. Thus in the usual transmitter the oscillator, the buffer amplifiers, the frequency doublers (if any), and the modulated amplifier (if any) are all operated in Class C. However, in radiotelephone transmitters it is sometimes desired to modulate a relatively small tube and to amplify the *modulated* output of that tube. For such "post modulator" amplification, the Class C condition is not suitable, and a Class B r-f amplifier is used; occasionally a second Class B stage follows. *Though the plate voltage and grid bias are the same as in audio work, there are some notable differences between audio and r-f Class B operation.*

1. The audio-frequency Class B tube has no signal input when there is no sound at the microphone, therefore any resting plate current is entirely converted into heat. On the other hand the radio-frequency Class B tube is never without grid input in the usual radiophone transmitter, for during silences unmodulated radio-frequency power is still being sent to the antenna; therefore, the tube is working at all times, though the level changes with modulation. (The statement does not hold true for Class B r-f stages of carrier-elimination transmitters or those using controlled carrier.) Thus a typical pair of quarter kilowatt tubes when used in push-pull Class B audio deliver 500 watts at full signal and none during a silence, but if used in Class B r-f they deliver 560 watts of r-f power during modulation peaks, while during a silence they maintain a carrier output of 140 watts—just ¼ the peak output. This 4-to-1 relation is essential in the operation of a post-modulated r-f amplifier, employing amplitude modulation as will be discussed later in chapter 6.

2. In Class B audio amplifiers a complete output wave form is secured by combining the half-wave output from each of two tubes. In r-f Class B amplifiers the audio wave form exists only as variations of an r-f carrier, hence is not exposed to distortion as long as these variations are maintained in proper time and form even though the *radio-frequency* wave form is distorted considerably. Thus, push-pull r-f Class B amplification is not essential for the prevention of distortion. If a single tube is used in a Class B r-f stage, it is necessary that the tube work into a tank circuit capable of converting the half cycle plate-current pulses into a wave form not too greatly different from a sine wave. Such a tank circuit must not have too small a ratio of *C* to *L*.

3. In an audio Class B amplifier, proper loading of the driver (to improve the regulation) is secured by using transformer coupling with a definite ratio. In radio-frequency circuits, a definite ratio is difficult to obtain. The problem often is solved by loading the driver with a fixed resistance. This load is proportioned to absorb at least 4 times as much power as the actual peak driving power.

4. In audio Class B amplifiers, the maximum plate dissipation occurs near full output. During periods of little or no signal the plate dissipation is very small. In radio-frequency amplifiers, the greatest dissipation occurs at carrier output (i.e., at no modulation) because here substantial power is delivered at fairly low plate efficiency. During high percentages of modulation, full output is alternated with very low output so the average dissipation is less than at carrier output.

5–3l. Computation of Class B R-f Amplifier Performance—Keeping the foregoing factors in mind, we shall proceed with a computation of Class B r-f amplifier performance.

Example: A Class B r-f amplifier is operated with a plate input of 0.75 amp and 4000 volts. Find the carrier power if modulation capability is to be 100 percent. The characteristics are given on Figure 5–19.

Solution: The problem is solved under the conditions existing during a positive modulation peak. At that point, the plate input will be twice as great or 1.5 amp at 4000 volts. Thus:

$$I_b \max = 1.5 \text{ amp}$$

The instantaneous peak plate current is found from: $i \max = 1.5/0.318 = 4.71$ amp. A line is drawn on the characteristic of Figure 5–19 through all points where the plate voltage is equal to twice the positive grid voltage. (See section 5–3g for details.)

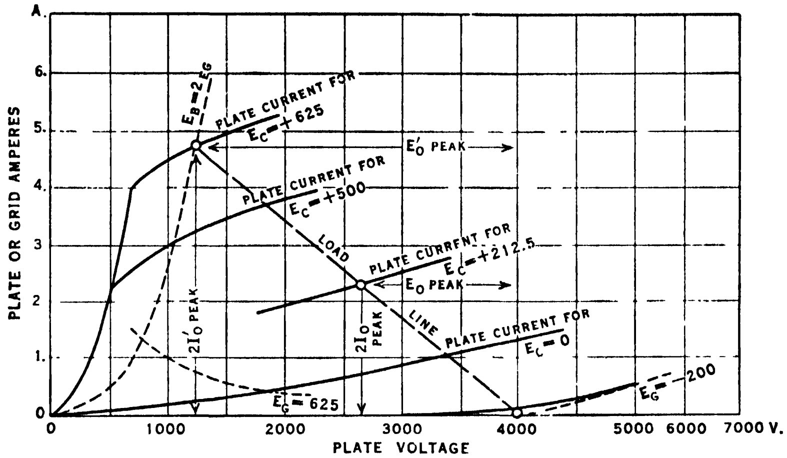


Fig. 5–19. Characteristics of Class B radio-frequency amplifier (see text).

Where this line crosses the maximum peak plate current we find:

$e_c = 625$ volts
$e_b = 1250$ volts

Subtracting this minimum instantaneous plate voltage from the applied plate voltage, we find the peak output voltage 4000 – 1250 = 2750 volts. The peak output current is equal to 0.5 times the peak plate current of the tube, or 0.5 × 4.71 = 2.35 amp.

The power output is now found: ½ peak voltage × peak current = ½(2750)(2.35) = 3235 peak output watts. This is the peak output power attained under a positive modulation peak. The carrier power is, for ordinary modulation, one quarter of this amount, or 809 watts carrier, but is much less for a controlled carrier and entirely absent in carrier elimination. The required load resistance is found by dividing the output voltage by output current = 2750/2.35 = 1170 load ohms. The plate efficiency at carrier output is: output/input = 809/3000 = 0.268 = 26.8 percent efficiency.

The required grid bias for a plate voltage of 4000 is found by inspection of the characteristic curves. Neglecting the curvature at low plate currents, a bias of – 200 volts will produce plate current cutoff. With this bias, a peak signal voltage of 825 volts is required to attain the maximum positive grid voltage of 625 volts. At carrier output, the signal voltage will be just half of this amount, or 412 volts peak. This would be, of course, 292 volts rms.

5–3m. Driving Power and Driver Loading—Examination of Figure 5–19 shows that, for a plate voltage of 1250 and a positive grid voltage of 625, the grid current will be 0.785 amperes. As the grid current is peaked rather than sinusoidal and flows only during half the cycle, the fundamental component peak value will be somewhat less than 0.5 times the peak current. The decimal 0.4 is estimated as a probable value. This makes the peak value of the fundamental component 0.4 × 0.785, or 0.314 amp. The required grid driving power is evidently one-half the product of this current and the peak signal voltage or ½(0.314 × 825) = 129 watts. This is the actual grid driving power required to produce a 100 percent positive modulation peak (at which point the output from the Class B amplifier is 3235 watts). To obtain good regulation from the driver, and consequently low distortion, the driver should be loaded with resistances to four times this power, that is, 516 watts. The difference of 387 between 516 watts and the actual driving power of 129 watts is dissipated in the resistance load. At carrier output the power dissipated in this resistor will be one quarter of this amount, that is, 387/4 = 96 + watts. The resistor should be capable of dissipating about 1½ times this power continuously.

5–3n. Bias Supply for Class B R-f Amplifiers—A point frequently overlooked in the design of Class B r-f amplifiers is the regulation of the grid bias supply. The peak grid current computed above was 0.785 amp. If adequate audio by-passing is provided, only the d-c component will flow through the bias supply. This component is estimated to be about 25 percent of the peak grid current, or 0.196 amp. However, this value is reached only during positive modulation peaks. In normal modulation positive peaks alternate with negative peaks. During the negative peaks the grid current is low. Thus if adequate audio-frequency by-passing is provided, only the average d.c. will flow through the bias supply. However, this increases during modulation; hence for low distortion the grid bias supply should possess sufficiently good regulation so that the grid bias voltage does not vary greatly in consequence of the changed current—say 5 percent voltage change as a maximum. Such regulation is easily obtained with a generator. Storage batteries are not without objection, for although they do not vary in voltage with momentary current changes, they do gradually become charged and assume a higher voltage, thus shifting the operating point. Vacuum tube rectifiers and filters may be used as grid-bias supplies but the regulation is seldom within the 5 percent limit unless the supply is made very large and stabilized by wasting much power in a bleeder resistance, or else is equipped with a regulating device with a very short time-lag.

5-3o. Plate Supply for Class B R-f Amplifiers—Good regulation of the plate supply of a Class B r-f amplifier is as necessary as for Class B audio, about 10 percent regulation being the maximum which should be tolerated from carrier only to full modulation. This regulation is quite possible with mercury-vapor rectifiers and filters of good design.

A frequent source of trouble is the operation of a Class B stage, either audio or r-f from a plate supply which also serves other stages. If this cannot be conveniently avoided, there should be interposed an additional filter section using a large condenser and choke.

5-3p. Practical Adjustment of Class B R-f Amplifiers—If the station computes power *output* by the indirect method (that is, based on the plate input and the 33 percent plate efficiency assumed by the Federal Communications Commission) the Class B stage should be adjusted as follows:

1. After proper neutralization apply plate voltage and grid excitation.

2. Gradually tighten the antenna coupling and at the same time increase the grid excitation. (Excessive grid excitation with loose coupling may damage the grid.) Do not exceed the grid current rating for Class C *telegraph* service.

3. Continue to increase the coupling until the d-c plate *input* is 6.5[4] times the required power *output*. For example, a station licensed for 1000 watts output should now take 6500 watts plate input.

4. Fix the antenna coupling at this point after readjusting the antenna tuning.

5. Reduce the grid excitation until the d-c plate input has come down to 3.0 times the required power *output*.

The stage is now properly adjusted and can follow modulation up to 100 percent. It will undoubtedly be found that the output is somewhat less than the licensed power (in the computed example 800 watts was obtained when the rated power was 1000), but this cannot be avoided with this method of power measurement.

If the power is computed by the direct method (that is, by antenna resistance and antenna current), proceed as follows:

1. After proper neutralization, apply plate voltage and grid excitation.

2. Gradually tighten the antenna coupling and at the same time increase the grid excitation. (Excessive grid excitation with loose coupling may damage the grid.)

3. Continue tightening the coupling until the antenna power is 4.4[5] times the licensed power output. As an example, for a licensed power of 1000 watts and antenna resistance of 15.1 ohms, the antenna current must reach:

$$\text{Test } I_a = \sqrt{\frac{\text{test power}}{R_a}} = 4400/15.1$$
$$= 17 + \text{amperes}$$

4. When this point is reached, make final adjustments to the antenna tuning, and fix the coupling at this point.

5. Reduce the grid excitation until the antenna power comes down to the licensed power. The antenna current will now be:

$$I_a = \sqrt{\frac{\text{licensed power}}{R_a}} = 1000/15.1 = 8.14 \text{ amperes}$$

The stage is now properly adjusted and is capable of following modulation up to 100 percent.

During the test output, the stage is operating substantially Class C and the antenna tuning may be adjusted for maximum antenna current. With reduced grid excitation, resonance will no longer be indicated by maximum antenna current. Antenna resonance is indicated by *minimum tank* current. Failure to appreciate this fact is responsible for most of the poor performance of Class B r-f amplifiers. It is generally advisable to tolerate day-to-day departures from exact resonance (due to changes in weather conditions, etc.) rather than to risk disturbing the modulation capability by frequent readjustment.

Alternative Method—Transmitters may be encountered where the design is such that the grid excitation cannot be raised sufficiently to obtain the test output. In this case, the tank current must be taken as an indicator of the plate efficiency, and the stage adjusted to operate at the required input or output without excessive efficiency. It is not always desirable to adjust for maximum possible efficiency, for the linearity of Class B and Class C stages is impaired thereby. Unless computations show a greater value, it is suggested that the plate efficiency at carrier output be limited to 25 percent. This is especially recommended when the power is based on the direct method, so that low efficiency does not involve a sacrifice in carrier power.

It is apparent that the output voltages may be computed by multiplying the reactance of the tank condenser by the observed tank current It. From this voltage, the plate efficiency is determined. For example:

Tank capacitance 0.0012 μf, frequency 1440 kc, plate voltage 4000, find the correct tank current.

The reactance of the tank condenser is first calculated at the working frequency. This is, as for any condenser, equal to $1/2\pi fC$ ohms, where the capacitance is in farads and 2π is, as usual, 6.28. This, for our example, makes the tank condenser reactance:

---

[4] This allows mod. peak to occur about 10 percent below the saturation point.

[5] This allows mod. peaks to occur about 10 percent below saturation.

$$1{,}000{,}000/6.28(1{,}440{,}000)(.0012) = 92 \text{ ohms}$$

The value 1,000,000 is used inasmuch as the capacitance was stated in microfarads while the equation calls for farads. If, now, the r-f voltage across the tank were known, we should be able to calculate the current through the tank condenser very quickly. This voltage is obtained as follows:

The efficiency of this type of stage is 0.785 (e_{peak}/E_b) where e_{peak} is the peak voltage during the cycle for full modulation, while E_b is the plate voltage. For reasons already given, the efficiency is assumed to be 25 percent. By substituting this in the equation and solving for e_{peak}, and then converting the peak value to rms, we have:

$$e_{\text{rms}} = 0.225E_b$$

which is correct only for 25 percent efficiency as assumed. For the present case this gives 0.225 (4000) = 900 volts. The current through the tank condenser is this voltage divided by the condenser reactance, which is 900/92 = 9.78 amp. The antenna coupling is then adjusted until the desired input (or output) is obtained with this tank current. After each change it will be necessary to readjust the grid excitation to restore the stated tank current.

These adjustment methods are conventional rather than ideal.

5–3q. Means of Improving the Efficiency of Class B R-f Amplifiers—The low efficiency of Class B r-f post-modulated-stage amplifiers (25 to 33 percent) causes a constant temptation to adjust for higher output efficiency, but such adjustments ordinarily result in defective linearity. A misadjusted Class B stage may either increase or decrease the percentage modulation, depending upon the nature of the misadjustment, but in either case the audio fidelity suffers.

Various methods to avoid this situation have been devised and have been put into use. These methods require added equipment and adjustments, hence each case must be analyzed to determine if such additions are warranted by the power saving, or whether the increased efficiency permits the use of smaller tubes at a considerable saving. The method adding least to the complexities of the transmitter is probably that of applying carrier-control to the Class C modulated stage. Since the controlled carrier becomes quite small during times when there is small modulation, it follows that at such times a following Class B r-f stage receives little excitation and therefore draws little plate input. In consequence the tube cools down more than if full carrier were used.

5–3r. The Doherty High-efficiency Class B R-f Amplifier—Another approach to the same problem is that of W. H. Doherty of the Bell Telephone Laboratories. In this case normal modulation with conventional uncontrolled carrier is used, that is, the Class C modulated stage is not special. It drives a following Class B r-f stage so chosen and adjusted that it is approximately fully loaded when the unmodulated carrier is being transmitted. Thus it is capable of following modulation downswings but cannot follow the upward modulation. A second tube is accordingly provided in the Class B stage, so connected and biased that it draws essentially no power at the carrier-only level and therefore does not deliver any power until the excitation goes above the carrier value. The result is that both tubes work at a larger percentage of their maximum rating with the increased efficiency common to full-load operation of nearly all electrical and mechanical devices.

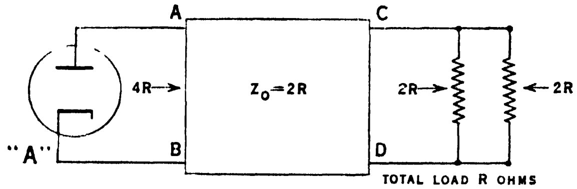
This result cannot be attained by mere parallel connection and unequal bias, for such a parallel connection would apply the output of the first (carrier) tube to the plate of the second (peak) tube, thereby preventing the second tube from contributing output *in proportion* to the excitation above carrier level.

In the circuit developed by Doherty, the output of both tubes is ingeniously combined by using an impedance inverting network between the carrier tube and the load. The effect of this network is to make it possible for both tubes to be connected to the load. When the peak tube begins to supply power, instead of decreasing the output from the carrier tube, it increases it. The effect can be understood by referring to Figure 5–20. Imagine the load to be represented by two resistances, each of $2R$ ohms, connected in parallel. At carrier output (or during negative modulation half-cycles) the peak tube is not functioning; the carrier tube, therefore, is feeding the load resistance through the impedance-inverting network. The load resistance is $2R + 2R$ in parallel or R ohms. At this point it is necessary to consider the action of the impedance-inverting network, because it is connected between the carrier tube and the actual load. The load resistance into which the carrier tube delivers its output is not the resistance R, but is the input terminals of the network. This impedance presented to the tube is expressed as:

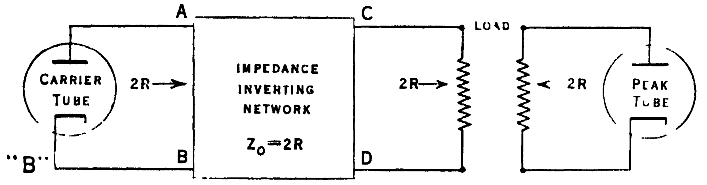
$$\text{Load on carrier tube} = \frac{Z_0^2}{\text{load}}$$

where Z_0 is the characteristic impedance of the network, and "load" is the actual load resistance, in this case, R. The characteristic impedance of the impedance inverting network depends upon the impedances which form it. The simplest form of such a network is a transmission line one-quarter wave length long. For this network the characteristic impedance is the well-known formula:[*]

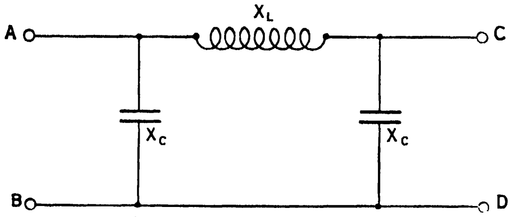
$$Z_0 = 276 \log 2D/d$$



DURING NEGATIVE MODULATION PEAKS THE CARRIER TUBE FEEDS THE ENTIRE LOAD. A RESISTANCE OF R OHMS. THE LOAD ON THE TUBE IS 4R OHMS. DUE TO THE ACTION OF THE IMPEDANCE CHANGING NETWORK



AT A POSITIVE MODULATION PEAK EACH TUBE FEEDS HALF THE LOAD 2R OHMS ON EACH TUBE



IMPEDANCE CHANGING NETWORK

THE DESIRED EFFECTS ARE SECURED WHEN $X_L=2R$. $X_C=2R$. THIS MAKES Z_0-2R ALSO. WHICH IS THE DESIRED CHARACTERISTIC IMPEDANCE

FIG. 5-20a,b,c.

where D is the distance between the wires, and d is the diameter of the wires. As it is obviously impractical to use a transmission line inside a transmitter (because of its length), the circuit shown in Figure 5-20c is used. In this circuit,

$$Z_0 = X$$

where X in the reactance of the inductance and either condenser. All three must have the same reactance (equal to $2R$) at the operating frequency to produce the desired effect. In the Doherty circuit, Z_0 is made numerically equal to *twice the effective resistance of the load.* Substituting these values, we find that, under carrier conditions, the load presented to the carrier tube is:

$$\text{Load on carrier tube} = \frac{Z_0^2}{\text{load}} = \frac{4R^2}{R} = 4R \text{ ohms}$$

When the excitation increases above the carrier value on a positive modulation half-cycle, the peak tube comes into action. At a 100 percent positive modulation peak, both the carrier tube and the peak tube are operating wide open, nearly saturated, and delivering approximately equal amounts of power. In this case we may assume that the carrier tube is delivering its half of the power into the left-hand resistance $2R$ (on Figure 5-20b), and the peak tube is delivering its half of the power into the right-hand resistance $2R$. Such a division is, of course, purely theoretical as there is actually only one load. It is useful because it shows clearly how the additional power delivered by the peak tube changes the apparent resistance into which the carrier tube is giving its power. When the peak tube was idle, the carrier tube supplied power to both resistances, thus having an actual load of R ohms. Now that the peak tube is delivering half the power, the carrier tube is supplying power to a load of $2R$ ohms. If the impedance inverting network was not used,

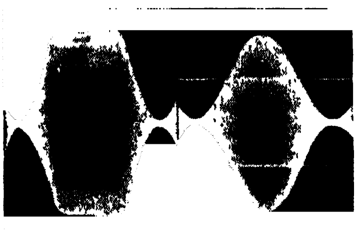


FIG. 5-21. Cathode-ray oscillograms of the plate potentials of Tube 2 (left) and Tube 1 during complete modulation in the Doherty amplifier.

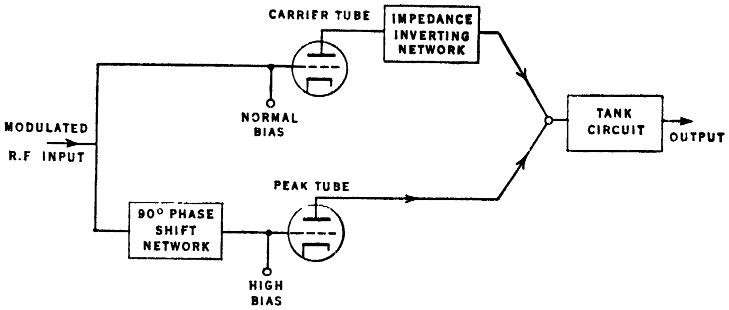


FIG. 5–22. Essential elements of Doherty amplifier.

this increase[6] in the load resistance would cause a reduction in the power supplied by the carrier tube as has been mentioned. Solving to find the load presented to the carrier tube with an impedance inverting network in place, we find:

$$\text{Load on carrier tube} = \frac{Z_0^2}{\text{load}} = \frac{4R^2}{2R} = 2R \text{ ohms}$$

This is a reduction in load resistance since the load on the carrier tube had been $4R$ at carrier output. This causes an increase in power to twice the carrier. Adding an equal amount of power from the peak tube, we have a peak output of four times the carrier, which is the correct amount for 100 percent positive modulation peaks. Furthermore, with proper adjustments, this power is added gradually with the excitation, thus satisfying the condition for linear amplification.

All impedance-inverting networks have the disadvantage of producing a 90° phase shift between the input and output voltage. If the output of the two tubes is to combine properly, it is necessary that an equal, or 90°, phase shift is given to the grid excitation of either tube. This can be accomplished conveniently by using the same sort of network in the grid circuit of the peak tube. As the grid circuit of this tube presents a reactance which varies with the amount of excitation, it is necessary to connect a fixed resistance from grid to cathode to provide a stable termination for the phase-shifting network. If this is not done, the amount of phase shift will vary with the modulation, thus causing erratic operation and serious distortion. Figure 5–22 shows a block diagram of the essential elements for a Doherty amplifier, and Figure 5–23 is a practical circuit diagram. Note how much more equipment is involved than in a conventional Class B r-f amplifier.

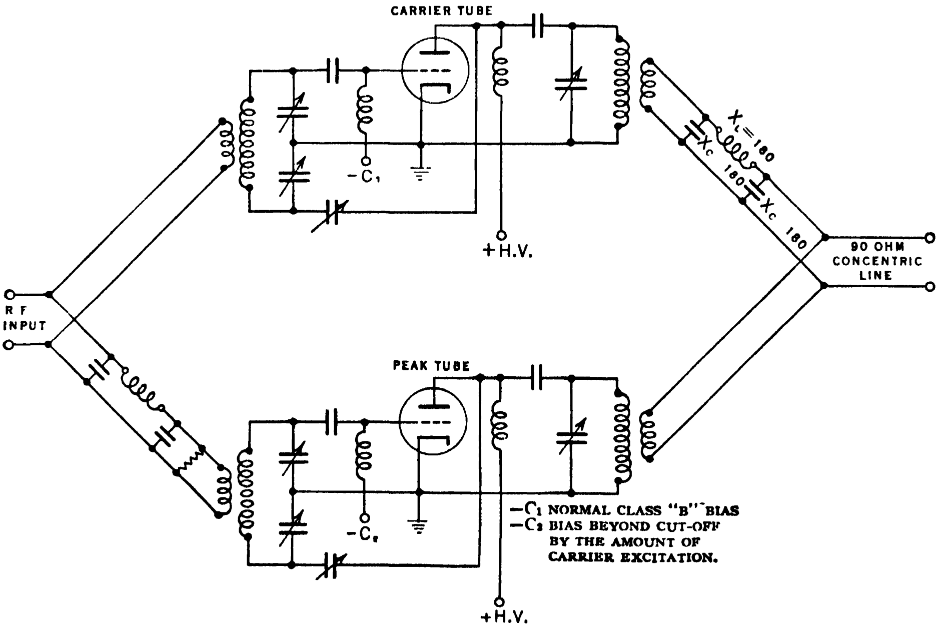


FIG. 5–23. Doherty amplifier circuit.

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[6] The load resistance at carrier output is R ohms if there is no impedance inverter in the circuit.

The load resistances required for Doherty amplifiers can be determined by the calculations which were explained under Class B r-f amplifiers, bearing in mind that two tubes are used which, when both are nearly saturated, should produce an output of four times the carrier power. The solution may be checked by using the formula,

$$R_L = \frac{0.314E_p^2}{W} = \frac{0.08E_p^2}{W_0}$$

where E_p is the d-c plate voltage and W_0 is the carrier power. This equation gives a rough approximation.

The characteristic impedance of the impedance-inverter will be just twice the value of R_L. The capacitances and inductances required are such that their reactances at the carrier frequency are numerically equal to twice R_L.

In the grid circuit, where there is no R_L, a fixed resistance must be used. Its value should be as low as possible without consuming too much r-f power. When the value has been chosen, twice that figure will be the required reactances for the inductance and capacitance in the grid circuit network.

The Doherty amplifier is not very well suited to high-frequency applications because at those frequencies the capacitances required in the inverting circuits become very small. This makes the amplifier easily affected by stray capacitances and tube interelectrode capacitances. In addition, it becomes increasingly difficult to hold the proper phase relations as the frequency is raised. It is likely that the use of tubes with low interelectrode capacitances will permit satisfactory operation at higher frequencies.

At low modulation percentages the peak tube is operating in the region near cutoff where the characteristics of tubes are not very uniform. This introduces distortion. Likewise the high efficiencies which are desired involve operating fairly close to saturation of the carrier tube. This is another source of distortion. A third source is the varying load on the preceding stage. It, therefore, becomes desirable to reduce the overall distortion. Western Electric uses feedback for this purpose.

5-4. Class C Amplifiers—A Class C amplifier is one in which the grid bias is appreciably more than is necessary to cut off the plate current when no exciting voltage (a-c grid input) is present, so that the plate current flows in the tube for appreciably less than one-half of each cycle: in fact flows only when excitation is present. Class C operation is confined to the radio-frequency stages of transmitters since the high plate-circuit efficiency is attained at the expense of large a-c grid input and high wave-form distortion. For r-f work this distortion is not objectionable as was explained in section 5-3k of this chapter.

The comparatively short pulses of plate current resulting from Class C operation have two important characteristics:

1. As the pulses become shorter, the efficiency rises.
2. As the pulses become shorter, the harmonic components in the output current become larger. With suitable tubes, considerable power may be obtained at two or even three times the excitation frequency by simply tuning the output tank circuit to the desired frequency.

Although Class C amplifier plate current forms are very complex and contain large harmonic components, the output voltage may be made a nearly pure sine wave by the flywheel action of the tank circuit. The explanation of this action is given later in Section 5-8c. This is not true if the tank circuit is out of tune or designed for extreme efficiency. All discussion to follow, however, will assume that a properly adjusted tank circuit is provided as this is usual in commercial equipment.

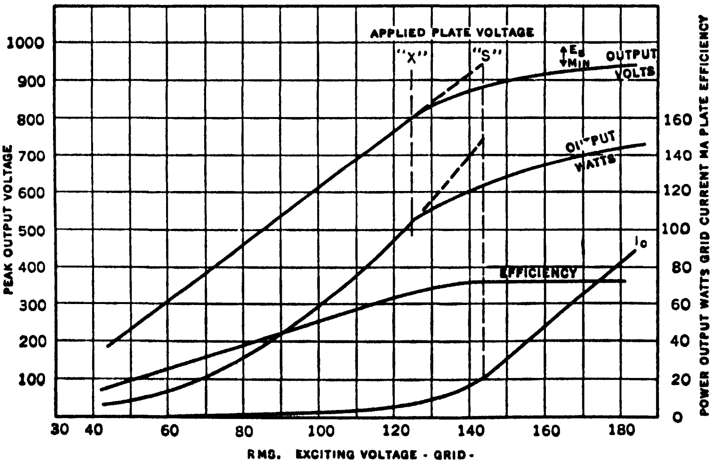


FIG. 5-24. Characteristics of 203A tube as Class C amplifier.

When this is the case, the output voltage is 180° out of phase with the excitation voltage, that is, the lowest plate voltage occurs when the grid voltage is the most positive, and the highest plate voltage is produced when the grid voltage is the most negative. This relation can be seen on Figure 5–26.

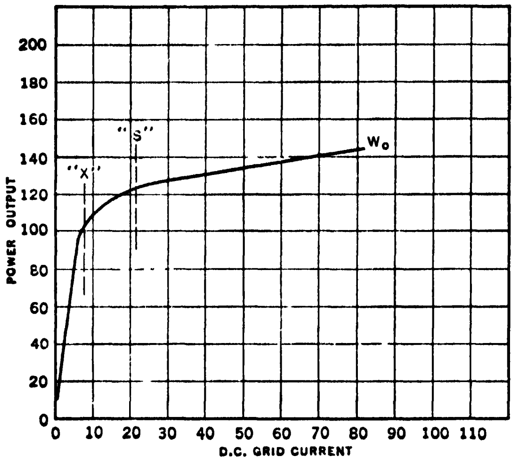
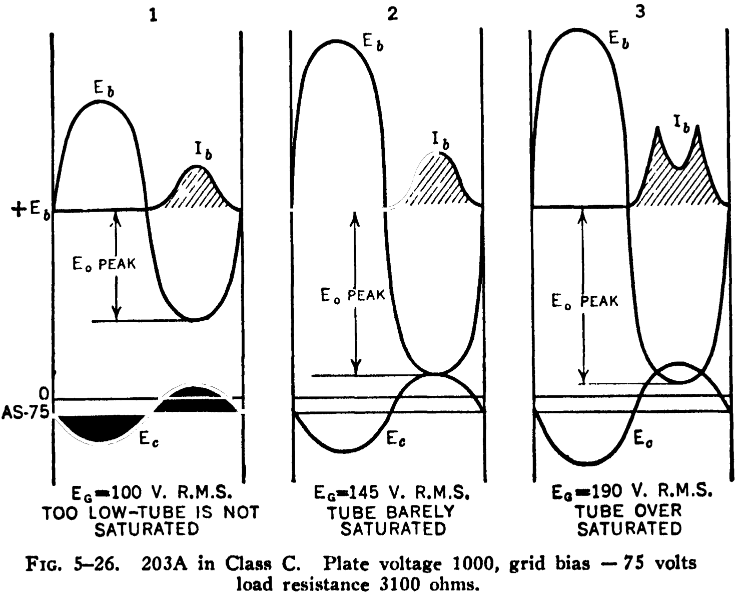


Fig. 5-25. Grid current versus power output of 203A tube operating as Class C amplifier.

5–4a. Excitation of Class C R-f Amplifiers—In Classes A and B amplifiers, an essential requirement was that the output voltage vary in direct proportion to the excitation voltage. In Class C amplifiers this restriction is removed, and it is necessary to study the effect of increasing the excitation to higher values. Figure 5–24 shows the performance of the somewhat old-fashioned 203A tube operated in Class C. The power output, peak output voltage, grid current, and plate efficiency are plotted against the excitation voltage. The curves given are for a load resistance of 3100 ohms, plate voltage 1000, and a bias of −75 volts. Up to the point marked *X*, the output voltage rises almost in exact proportion to the excitation voltage. In fact, except that the bias is slightly high, the tube is operating as a Class B r-f amplifier up to this point. This point is where the minimum instantaneous plate voltage (the difference between the plate voltage and the peak output voltage) is about twice as high as the peak positive grid voltage (peak excitation voltage less the bias). At this point the grid current and, consequently, the driving power, are fairly low. The plate efficiency is high—66 percent in this case. This is slightly higher than is obtained at full output with Class B because of the higher bias and consequent shorter plate current pulses. Class B employs lower bias to obtain the most linear relation between excitation and output voltage. Beyond the point marked *X*, the output increases more slowly. This is more evident if the output is plotted against the grid current, as has been done on Figure 5–25. The point marked *S* just beyond the knee of the curve is termed the *saturation point*. The point *S* is also marked on Figure 5–24, although here the knee is less pronounced. Note that at point *S* the minimum instantaneous plate voltage is just about equal to the positive grid voltage. Here the grid current and driving power are fairly high, although not unreasonably so, and the plate efficiency has reached its maximum; 72 percent in this case. If the excitation is increased beyond *S*, the tube is said to be oversaturated. As the peak output voltage approaches the plate voltage as a limit, the grid current and driving power become very high. With the increase of output voltage (however slight) it



E_G=100 V. R.M.S. TOO LOW–TUBE IS NOT SATURATED

E_G=145 V. R.M.S. TUBE BARELY SATURATED

E_G=190 V. R.M.S. TUBE OVER SATURATED

Fig. 5–26. 203A in Class C. Plate voltage 1000, grid bias −75 volts load resistance 3100 ohms.

would normally be expected that the plate efficiency would increase in proportion. That it does not do so is due to the fact that when oversaturated the shape of the plate current wave is greatly disturbed, thus preventing further increase in plate efficiency.

The relation between plate voltage, grid voltage, and plate current flow is shown more clearly on Figure 5-26. Each of the three sections represent a single r-f cycle of operation. In 1, the grid excitation is too low, the tube is not saturated, and the peak output voltage is considerably lower than the plate voltage. In this condition the plate voltage could be raised or lowered without affecting the output. In 2 the grid excitation is increased just to the saturation point. The peak output voltage is nearly as large as the plate voltage. With this excitation a reduction of plate voltage will immediately reduce the output (by limiting the output voltage). However, the output will not rise if the plate voltage is raised. If a modulated amplifier is operated with this amount of excitation, it will "modulate down." In 3 the excitation is more than enough to produce saturation. The output voltage is practically the same as in 2. Note the unusual shape of the plate current wave. During the portion of the cycle that the positive grid voltage *exceeds* the plate voltage, the plate current *falls* rapidly. This causes a dip in the center of the plate current wave and reduces the output current. It is this effect that limits the output voltage since, if the plate voltage falls below the grid voltage for too large a portion of the cycle, the output current will not be large enough to maintain the output voltage. (The output voltage and current have a fixed ratio, determined by the load resistance.) This automatically limits the output voltage. In practice, this balance is reached when *the peak output voltage is nearly equal to the plate voltage.* This is the basic principle of plate modulation. *If the excitation is sufficient to saturate at the highest plate voltage reached, the output voltage will approximately equal the plate voltage at any lower value.* Thus for 100 percent plate modulation, it is necessary that the excitation be sufficient to saturate the tube at twice the normal plate voltage. This, of course, makes the tube considerably oversaturated at the normal plate voltage and requires very high driving power.

5-4b. Class C Grid Bias—The definition of Class C amplifiers does not specify any particular bias, Class C being defined as operating with *any bias beyond* cutoff. Experience has shown that, for unmodulated amplifiers (such as in telegraph transmitters), bias of about twice cutoff is about right. Higher bias will produce slightly greater efficiency, but the increase is not usually worth the increased driving power (greater excitation voltage is necessary to overcome the higher bias). In plate-modulated stages, it is desirable that the bias be somewhat above cutoff at the highest plate voltage. A bias of three times cutoff (1.5 times cutoff for the highest plate voltage) for the normal plate voltage is usually recommended. In neither case is the bias critical, and satisfactory results can be obtained with considerable different values.

In plate-modulated Class C amplifiers, the high grid current and driving power required because of oversaturation at the normal plate voltage can be considerably reduced by providing some resistance (gridleak) in series with the grid bias supply. At carrier plate voltage, a moderate increase in the grid current will add to the bias and thereby reduce the unnecessarily high positive grid swing. As the plate voltage rises during a positive modulation peak, and the oversaturation becomes less, the grid current will fall, reduce the bias, and increase the positive grid swing.

It is entirely practical to supply the entire bias voltage from a gridleak. Tests have shown that better modulation is obtained than with fixed bias. Gridleak bias has the disadvantage of being lost if the excitation fails, as for example the failure of a tube in a buffer stage. Without bias, many tubes draw dangerously high plate current. For this reason, it is considered good engineering practice to use a combination of fixed bias and gridleak bias, the fixed bias being just large enough to hold down the plate current in case of excitation failure. With gridleak or combination bias, it is necessary that the bias at carrier plate voltage be greater than that specified, or it may fall too low when the grid current falls during a positive modulation peak. No figures will be given as the bias is not critical. The grid current indicated by a meter will not change since each positive modulation peak is immediately followed by a negative peak during which the grid current rises approximately an equal amount. The meter is, of course, unable to follow these changes.

5-4c. Computations of Class C Amplifier Performance—In computations of Class C amplifier performance the difficulty arises that the plate-current wave form is very far from sinusoidal under some conditions. However, a practical method of calculating performance becomes possible if certain operating points are assumed. Accordingly, in the following discussion it is assumed that the plate-current will flow for somewhat less than ½ cycle as in Figure 5-26 (150 electrical degrees), that for a frequency-doubling amplifier it will flow for about 90 electrical degrees as in the upper left diagram, Figure 5-27, and that in the case of a frequency tripler it will flow for about 60 electrical degrees as in the upper right-hand curve of Figure 5-27. In each case the assumed current pulse lasts about ½ cycle *at the output frequency.* With these assumptions working constants may be stated as follows:

For the ordinary Class C r-f amplifier at saturation

The average plate current I_b $= 0.27 \times i_b$ max
The peak output a.c. $= 0.46 \times i_b$ max
The peak 2nd harmonic current $= 0.255 \times i_b$ max
The peak 3rd harmonic current $= 0.07 \times i_b$ max

Where the bias and drive are chosen to produce maximum 2nd harmonic and the plate circuit is tuned to it:

The average plate current $I_b = 0.185 \times i_b$ max
The peak output a.c. (2nd harmonic) $= 0.271 \times i_b$ max

When adjusted for tripling frequency:

The average plate current $I_b = 0.112 \times i_b$ max
The peak output a.c. $= 0.172 \times i_b$ max

i_b max is the dynamic peak plate current and can be found from either the curves for the tube or in some cases the known d-c plate current I_b.

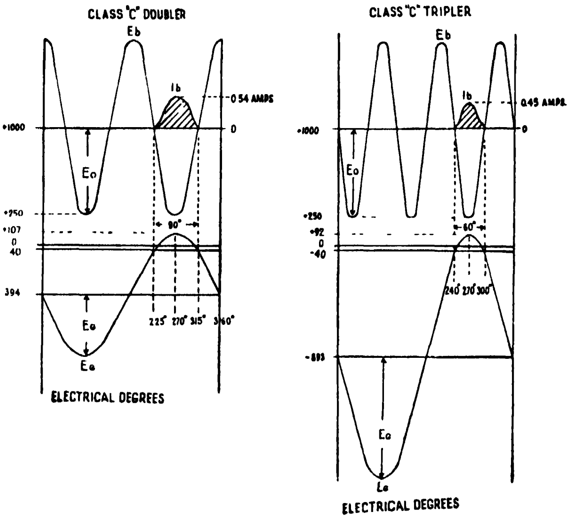


FIG. 5–27. 203A tube as Class C frequency multiplier.

The relations between plate voltage, grid voltage, and plate current for frequency multipliers are shown in Figure 5–27. As a general rule, frequency multipliers are not operated at the saturation point, as to do so would require unreasonably high driving power. However, if the driving power is available, it is entirely possible to saturate the grid and thereby obtain high output and high plate efficiency.

5–4d. Plate Dissipation of Class C Modulated Amplifier—An interesting point arises when a Class C amplifier is plate-modulated. Assume the d-c plate input is 150 watts, and the r-f output is 100 watts, leaving 50 watts dissipated on the plate. Now under sustained 100 percent modulation, the plate input will be 225 watts—150 watts d.c. from the plate supply, and 75 watts of audio power delivered from the modulator. The output rises in the same proportion, 1.5 times, to 150 watts. This now leaves 225 — 150 or 75 watts to be dissipated at the plate. Although sustained modulation of 100 percent is not often applied, it is a possibility and the transmitter should allow for it. Accordingly, the plate dissipation of a modulated amplifier must be limited to ⅔ of the rated dissipation. Thus, in the above example, the tube should have a dissipation rating of *at least* 75 watts.

Example: Class C Telegraph Operation—Given the characteristic curves shown on Figure 5–28, plate voltage 1250, plate current 0.175 amp, find the power output, load resistance, plate efficiency, grid bias, and excitation voltage for Class C telegraph operation.

Solution: The peak plate current can be found from the d-c plate current specified: $i_b \text{ max} = I_b/0.27 = 0.175/0.27 = 0.648$ amp. The constant 0.27 is explained in Section 5–4c. This plate current must be attained at the point where the plate voltage and positive grid voltage are equal. From Figure 5–28 it can be seen that the required values are:

$$e_b \text{ min} = 138 \text{ volts}$$
$$e_c \text{ max} = 138 \text{ volts}$$

The output current is determined from the peak plate current just found, and the factor given in Section 5–4a as 0.46×0.648 amp $= 0.298$ peak amp, which is converted to rms in the usual way: $0.707 \times 0.298 = 0.211$ amp.

The output voltage is the difference between the plate voltage and the minimum instantaneous plate voltage, or $1250 - 138 = 1112$ volts peak. This also can be converted to rms, becoming $0.707 \times 1112 = 785$ volts rms.

The power output can be found conveniently from the peak output voltage and peak output current as in previous examples: ½ peak volts × peak amperes, or $\frac{1}{2}(1112)(0.298) = 166$ output watts. If rms values are used for the output voltage and output current, the factor ½ is omitted, thus:

$$\text{Power output} = 785 \times 0.211 = 166 \text{ watts}$$

The plate efficiency is, as usual, the output power divided by the plate input, or $165/(1250 \times 0.175) = 75.8$ percent. (This efficiency is higher than that shown on Figure 5–24 because of the higher plate voltage.)

The plate dissipation is the difference between input and output, or 218.5 — 166 = 52.5 watts plate loss.

The required loading may be expressed as a resistance and is determined by dividing the output voltage by the output current:

$$R_L = 1112/0.298 = 3730 \text{ load ohms}$$

The grid bias for Class C operation is not critical but should be at least twice cutoff; that is, $2(E_b/\mu) = 2 \times 1250/25 = 100$ volts. Slightly higher values may be used with beneficial results.

The peak excitation voltage again must exceed the grid bias by the required peak positive grid voltage; that is, it equals $138 + 100 = 238$ peak grid a-c input volts or $0.707 \times 238 = 168$ rms grid input

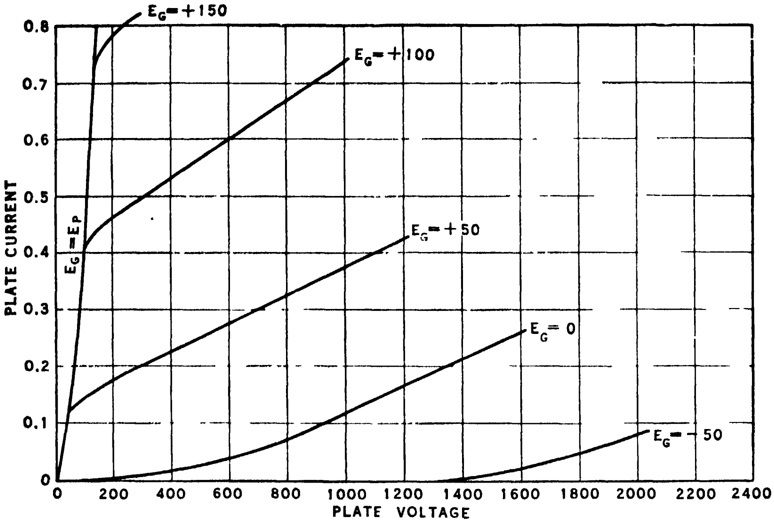


FIG. 5–28. Plate characteristics of 203A tube.

volts. Of course, with higher bias more excitation voltage will be needed.

Example: Class C Amplifier-Telephone—The tube of Figure 5–28 is to be plate-modulated 100 percent. The carrier plate input is 0.100 amp at 1000 volts. Solve for the bias, excitation voltage, output voltage, approximate plate efficiency, and plate dissipation.

Solution: This problem is solved by determining the conditions for saturation at the highest plate voltage reached, namely, 2000 volts. (Twice the unmodulated value.) At this voltage, the plate current will be increased to twice the unmodulated value, or 0.200 amp; thus the peak value, by the method just used, is .200/.27 = 0.74 amp. Note that this peak plate current is more than *seven times* the current shown on the plate ammeter. Inability to produce this high current is sometimes the reason that old tubes may deliver the carrier power but fail to modulate properly.

The peak plate current is, as before, to be attained with a grid voltage equal to the plate voltage. From the characteristic curves we find the required values; this time:

$$e_b \text{ min} = 150 \text{ volts} = e_c \text{ max}$$

The output current again can be found from the peak plate current and the constant 0.46, which gives 0.341 amp output peak current.

The peak output voltage found, as in example 1, is 2000 − 150 = 1850 peak volts or 0.707 × 1850 = 1308 rms output volts.

The values already found give the power output: as before, $P_{out} = \frac{1}{2}$ peak volts × peak ampere = $\frac{1}{2}$ × 1850 × 0.341 = 315 watts. *This is the power delivered on a positive modulation peak* (at the instant the plate voltage reaches 2000 volts). *The carrier output* (at 1000 volts plate voltage) will be one quarter of this *amount*, or 78.8 watts.

The plate efficiency may be computed either at carrier output or at a positive modulation peak—the value is the same as far as can be determined by a simple solution. Dividing output by input: efficiency = 315/(200 × 0.2) = 78.8 percent.

This value is somewhat higher than that given on Figure 5–24 because the loading is lighter (load resistance is higher) and the bias is greater.

The grid bias recommended is twice cutoff at the highest plate voltage, or four times cutoff at the carrier plate voltage:

$$-4E_b/\mu = -4(1000)/25 = -160 \text{ volts bias needed}$$

Again the excitation voltage must be greater than the bias by the amount of the positive grid voltage required: 150 + 160 = 310 volts peak a-c grid input, or 219 rms volts grid input.

The load resistance is determined by dividing the output voltage by the output current: 1850/0.341 = 5420 load ohms.

At carrier output, the plate dissipation is watts input minus watts output, or approximately (1000 × 0.100) − 78.8 = 21.2 watts plate loss. Under sustained modulation, this may be increased by 50 percent, making the highest plate dissipation to be anticipated 31.8 watts.

Example: Frequency Doubler Class C—It is desired to operate a 203A tube as a frequency doubler at a plate voltage of 1000 and a plate current of 100 ma. Determine the output, plate efficiency, bias, and excitation voltage.

Solution: As has been stated, frequency doublers are not operated at the saturation point because of the excessive driving power required to do so. Accordingly, we will assume a peak output voltage of only 75 percent of the plate voltage. This will produce a plate efficiency of about 50 percent which is a reasonable value. Thus we assume a peak output of 750 volts. In consequence the minimum plate voltage becomes $E_b - 750 = 1000 - 750 = 250$ volts.

The peak plate current to be attained can be determined by dividing the d-c plate current by 0.185, that is, $0.100/0.185 = 0.54$ amp. This current is reached when the plate voltage reaches its 250-volt minimum value (found above). From the characteristic curves shown in Figure 5–28, it is seen that a grid voltage of + 107 volts is necessary. To operate satisfactorily as a doubler, the plate current flow must be restricted to 90 electrical degrees. This means that the grid voltage must pass through cutoff at the angles of 225°, reach a maximum of 107 volts at 270°, and on returning pass through cutoff again at 315°. Cutoff is, of course, found by dividing the plate voltage by the amplification constant. Fortunately, the plate voltage is equal to the applied plate voltage at both times, whereupon cutoff bias $= E_b/\mu = 1000/25 = -40$. These values can be seen on Figure 5–27 but this is not the desired value of working bias. The excitation required to produce these conditions is determined from the equation:

$$e_c \text{ peak} = \frac{(e_g \text{ max}) - (E_c \text{ cutoff})}{1 + \sin 225^\circ}$$
$$= \frac{107 - (-40)}{1 - 0.707} = 501$$

peak r-f grid input volts. However, the grid is to go positive by only 107 volts; hence the required grid bias is $107 - 501 = -394$ volts bias. Note that this bias is nearly *ten times* cutoff. With lower bias the plate efficiency and output would fall rapidly.

The current output is: $i_p \text{ max} \times 0.271 = 0.54 \times 0.271 = 0.145$ peak amp, hence:

$$\text{Power output} = \tfrac{1}{2}(0.145)(750) = 54.7 \text{ watts}$$

The plate efficiency is found by dividing this by the plate input: efficiency $= 54.7/(1000 \times 0.100) = 54.7$ percent. This efficiency is typical of frequency doublers *when operated with sufficient bias.* If higher plate current (and higher output) is desired, even higher bias will be required. To keep the bias to a reasonable figure, it is necessary that tubes having a high amplification factor be used, such as the one chosen for this example. Because of the high excitation voltage required, doublers do not contribute, as a rule, much voltage amplification. A moderate amount of power amplification may be secured, but because of the comparatively low plate efficiency, it is inadvisable to operate the final stage of a transmitter as a doubler.

Example: Frequency Tripling Class C Amplifier —A 203A tube is to be operated as a frequency tripler. The input is to be 0.050 amp at 1000 volts (experience having indicated that greater input will require excessive bias voltages), with the expectation of realizing an output of about 25 watts.

Solution: As has been mentioned, frequency multipliers are not operated at the saturation point because to do so would require excessive driving power. Arbitrarily limiting the output voltage to 75 percent of the plate voltage, we assume that peak output = 750 volts, hence e min $= 1000 - 750 = 250$ volts.

The peak plate current can be found by dividing the d-c plate current by the factor 0.112; that is, 0.50 amp 0.112 = 0.446 peak amp. As this plate current must be obtained with the minimum instantaneous plate voltage (found above) of 250 volts, by reference to the characteristic curves on Figure 5–28, we find that a peak grid voltage of + 92 volts must be reached. To show the desired plate efficiency, it is necessary that the plate current flow in a frequency tripler be limited to not over 60 electrical degrees of every grid cycle (180 electrical degrees at the triple frequency of the plate circuit). This means that the grid voltage must pass through cutoff at the electrical angle of 240°, reach a maximum of 92 volts at 270° and on returning pass through cutoff again at 300°. Cutoff is, of course, found by dividing the plate voltage by the voltage amplification factor of the tube as in the doubler example and is again: cutoff $= -40$ volts. These values can be seen on Figure 5–27. The excitation voltage required to produce this condition may be found from the equation:

$$e_c \text{ peak} = \frac{e_g \text{ max} - E_g \text{ cutoff}}{1 + \sin 240^\circ} = \frac{e_g \text{ max} - E_c \text{ cutoff}}{1 + \sin 240^\circ}$$
$$= \frac{92 - (-40)}{1 - 0.866} = 985 \text{ volts}$$

The grid bias is equal to this voltage less the desired positive grid swing of 92 volts, or $92 - 985 = -893$ bias volts required. Thus the bias is nearly as great as the plate voltage (negative, of course) and the excitation voltage is actually greater than the output voltage. The extremely high bias required indicates that it is impractical to obtain any appreciable amount of power with frequency tripling. The peak output current obtained with this bias is $i_p \text{ max} \times 0.172 = 0.446 \times 0.172 = 0.076$ peak output amp. The output voltage was initially taken as 750. Power output $= \tfrac{1}{2} \times 750 \times 0.076 = 28.8$ watts.

The plate efficiency may be determined easily as watts output/watts input $= 28.8/1000 \times 0.050 = 57.6$ percent. This output and efficiency can be obtained only with the very high bias already computed. With less bias, the output power will be greatly reduced even though the plate input may be higher.

5–4e. Practical Adjustment of Class C Amplifiers—1. *Intermediate Stages*—After neutralization apply reduced plate voltage and tune the tank circuit for minimum plate current. After reaching the proper setting, the plate voltage may be raised to the full value. Now check the grid current. If no meter is provided, it is advisable to connect one in the circuit temporarily. Adjust the excitation tap on the preceding amplifier (or oscillator) until the grid current is the amount recommended by the manufacturer for Class C service.

This procedure is followed through on each intermediate stage, in succession.

2. *Frequency Multipliers*—In adjusting frequency multipliers, it is essential to have sufficient bias voltage and excitation. If grid leak bias is used, both will be obtained more or less automatically if the grid current is kept at the proper point by adjusting the excitation control or tap on the preceding stage. If fixed bias is used, it should be adjusted with the aid of a voltmeter. After obtaining the desired bias, correct excitation can be approximated by adjusting the excitation tap until a small amount of grid current is indicated. With full bias and full plate voltage (reduced plate voltage if the plate current is dangerously high when off resonance) tune the tank circuit for minimum plate current. As two or more points of minimum current are sometimes found, it is necessary to identify the proper point by using a wavemeter coupled loosely to the tank coil. When minimum plate current has been located at the proper harmonic, adjust the grid excitation for maximum output. This can be done most easily by noting the deflection on the wavemeter. *Note:* A heterodyne type of frequency meter should not be used for this purpose. The absorption type wavemeter, consisting of a condenser, coil, and current indicating device, should be used.

3. *Final Amplifiers—Telegraph*—After neutralization, apply reduced plate voltage, and, with the antenna circuit open, tune the tank circuit for minimum plate current. Shut off the plate voltage, and close the antenna circuit, using loose coupling. Apply reduced plate voltage and tune the antenna circuit for maximum antenna current. When the correct point has been found, gradually tighten the coupling until the plate current is the same fraction of the desired plate current as the reduced plate voltage is of the full plate voltage. Now apply full plate voltage and make final adjustment to the coupling until the desired plate current is drawn. After each change to the coupling, it may be necessary to retune the tank circuit slightly for minimum plate current. When finished, note the grid current. Adjust the excitation tap (or other control) until the grid current is the value recommended for the tube type in use. If the excitation was far from the correct value, it may now be necessary to readjust the antenna coupling to hold the desired plate current.

4. *Final Amplifiers—Telephone (Plate Modulated)*—After neutralization, apply reduced plate voltage, and, with the antenna circuit open, tune the tank circuit for minimum plate current. Disconnect the plate voltage, close the antenna circuit, and adjust for loose coupling. Again apply reduced plate voltage and tune the antenna circuit for maximum antenna current. When obtained, gradually tighten the coupling until the plate current has the same relation to the desired plate current as the reduced plate voltage has to the full plate voltage. (For example, if the plate voltage has been reduced to one-half adjust the coupling until the plate current is likewise one-half of the desired amount). After each change in coupling, it may be necessary to make a slight readjustment to the tank circuit for minimum plate current. Now apply full plate voltage and note the grid current. (A grid current meter is essential for proper adjustment of a Class C modulated amplifier.) Adjust the excitation control until the grid current is at the point recommended by the manufacturer of the tube for Class C plate modulated service. After obtaining the correct grid current, it may be necessary to make a final adjustment to the coupling in order to bring the plate current back to the exact amount desired.

Final adjustment of the grid excitation should be made by an actual modulation test. Insufficient excitation will cause a flattening out on the positive modulation peaks. This may be observed on an oscilloscope or, if apparatus is available, the distortion may be measured. The excitation should be adjusted until the amount is found which produces the best wave shape (lowest distortion) at approximately 90 percent modulation. The grid current should be carefully noted and maintained at the same value thereafter. This grid current may be higher than that recommended by the manufacturer as experience often shows a moderate excess of excitation gives better results.

Lacking proper instruments, a crude test of the excitation can be made by noting the Class C plate current during modulation. Up to 80 or 90 percent modulation, the plate current should be entirely steady. When the modulation exceeds 100 percent, the plate current should *rise*. A *dip* in plate current indicates either insufficient excitation, a defective tube, or low filament voltage. (A slight dip, 5 percent or less, may be experienced if Class B modulators are used and the modulator load causes a drop in the Class C amplifier plate voltage.)

5-5. Vacuum Tube Oscillators—A vacuum tube is capable of serving as an oscillator because of its ability to amplify. Since the output of the tube is greater than the input, it is possible to return a portion of the power from the tube's output circuit to the grid and thereby make the tube supply its own excitation. Provided that the voltage fed back to the grid is of sufficient magnitude and is in the correct phase relationship with respect to the voltage across the plate-circuit load impedance (approximately 180°), the circuit will oscillate. This type of oscillation is known as regenerative oscillation.

An oscillator usually serves as a source of r-f or audio power. For reasons of efficiency, it is normally operated with a high value of grid bias, such as in a Class C amplifier. The bias is commonly obtained by means of a gridleak, because gridleak provides low (or zero) initial bias and permits quick oscillator starting when power is applied; otherwise no plate current would flow as a result of the high bias. As soon as oscillations start, the bias automatically assumes its normal value.

The plate efficiency of an oscillator is lower than a similar amplifier since the oscillator must supply excitation to its grid circuit. The efficiency of a well-designed oscillator will be in the order of 50 percent.

A regenerative oscillator operates when the grid exciting voltage is sufficiently large and of such a phase relationship that it is approximately 180° displaced with respect to the voltage in the output circuit. Since the two ends of an inductor normally assume an opposite polarity, an obvious method of obtaining such a phase relationship is to employ an inductor, one end of which is connected to the plate and the other end to the grid of the oscillator tube. This inductor may then be tuned to the desired operating frequency by means of a suitable condenser. The cathode must be connected to an intermediate point of this tuned circuit, and suitable blocking condensers and choke coils are employed to isolate the d-c and a-c voltages. Several practical oscillators employ these basic ideas.

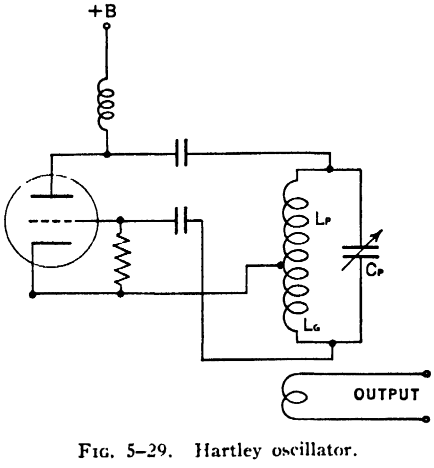


Fig. 5–29. Hartley oscillator.

5–5a. The Hartley Oscillator—In the Hartley oscillator the cathode connection is made to a tap on the coil. Figure 5-29 shows the shunt-feed form of this circuit. At low frequencies, the a-c grid and plate voltages are approximately proportional to the sections L_g and L_p, respectively, but at high frequencies the stray capacitances complicate the circuit, adding numerous paths which do not appear in this simple diagram and which make it difficult to maintain the desired phase relationship between grid and plate voltages without resorting to certain "dodges" such as independently variable plate and grid condensers which destroy the single-control feature of this circuit. However, this is an effect encountered with all oscillators at high frequencies. The Hartley circuit, nevertheless, remains one of the most tractable of oscillators. Incidentally, this circuit is not an inductively coupled feedback arrangement in the ordinary sense; the coil may be divided and the two sections shielded from each other without stopping oscillations entirely, provided the experiment is made at a reasonably low frequency where the extra capacitances and wire lengths are not objectionable.

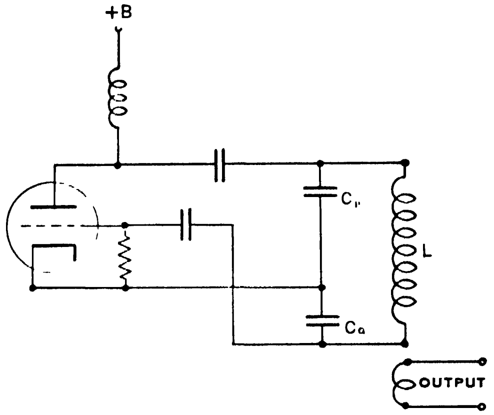


Fig. 5–30. Colpitts circuit.

5–5b. The Colpitts Oscillator—In Figure 5-30 is shown the Colpitts version of the same general idea. In this circuit the cathode connection is made to the common point of the tuning condensers, that is, the Colpitts circuit uses two condensers in series across one coil, in contrast to the Hartley circuit which uses two coils across one condenser. Whereas in the Hartley circuit the feedback is controlled by changing the relative inductance of L_p and L_g, control in the Colpitts circuit is accomplished by changing the relative capacitance of the two condensers. Thus in the former circuit a tap is moved on a coil; in the latter circuit two condensers are adjusted.

Each of these circuits can claim superiorities. From the operator's standpoint the Hartley circuit is less convenient to adjust as to feedback but simpler to tune, though neither side of the condenser is at ground potential and hence an insulated shaft drive must be used or hand capacitance will be encountered. In practice certain advantages are obtained by use of the Colpitts circuit since a variable inductance can be used over a wide frequency range with fixed condensers without disturbing the feedback voltage ratio.

5–5c. The Meissner Oscillator—An oscillatory circuit of the regenerative type which is sometimes encountered unintentionally is that of Meissner. This resembles the Hartley circuit except that the coils L_p and L_g are not tuned but are coupled to an external circuit which *is* tuned. At times an r-f amplifier unintentionally has both its grid and its plate circuit coupled to a near-by pipe or wire in such a manner as to produce a Meissner-circuit "parasitic" oscillation. Because of the higher frequencies employed today, this circuit is seldom used intentionally, simplicity being a main requirement at high frequencies, and it is to be remembered that the Meissner circuit was devised when 540 meters was a "short wave." The Colpitts oscillator is somewhat less subject to parasitic oscillation than the Hartley circuit, but either is subject to the Meissner type.

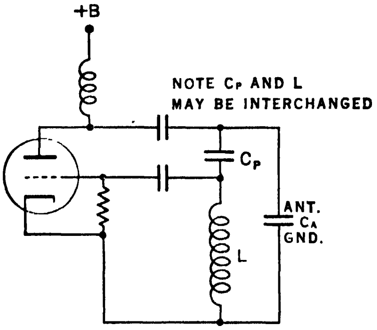


Fig. 5–31. Ultraudion oscillator.

5–5d. The Ultraudion Regenerative Oscillator—The ultraudion circuit (frequently miscalled "ultra-audion") is historically one of the oldest of all oscillators. Several circuits are known by this name, which is correct as they were described originally under a common name, and all have common features. In Figure 5–31 is shown one form which may be thought of as a cross between the Hartley and Colpitts circuits and may at first appear inoperative. Another form which is in extensive use for low-power high-frequency oscillators is obtained by adding a second coil between the upper ends of C_A and C_P, removing the plate stopping condenser and choke, and feeding the plate supply through this second coil. This is an exceptionally vigorous oscillator at high frequencies. The tuning can be accomplished either at C_P or C_A.

5–5e. The Tuned-plate Tuned-grid Oscillator—We come now to another early and very useful oscillator of the regenerative type developed by E. H. Armstrong and commonly known as the "tuned-plate, tuned-grid," or "TPTG." Its two tuned circuits are independent except as coupled through the interelectrode plate-grid capacitance of the tube. Figure 5–32 shows a shunt-feed form, but one of the merits of this circuit is its ability to use series feed without causing the tuning condensers to become "hot" on their rotor sides, at either r.f. or d.c., thus eliminating the necessity for r-f chokes. However, the principal merit of this circuit is that the required feedback phase is more easily established through the ability to tune the grid and plate circuits independently, thereby providing any desired impedances. The two circuits are *not* working at the same natural frequency; it is necessary that the tuned-plate circuit be inductive in nature, hence nonresonant, but nearly so. If a high ratio of C to L is used, good stability and good efficiency are possible at the same time. If the tuned grid circuit takes the form of a quartz crystal, this circuit is our familiar crystal-controlled oscillator of Figure 5–33, by means of which many stations—commercial and amateur—are controlled. No basic change is introduced by substituting a tetrode or pentode as the reduced feedback is more than balanced by the greater sensitivity of such tubes. Another interesting variant is the replacement of the tuned grid circuit by a semiresonant choke coil. This arrangement of a tuned-plate and semi-tuned grid offers single control as its main merit.

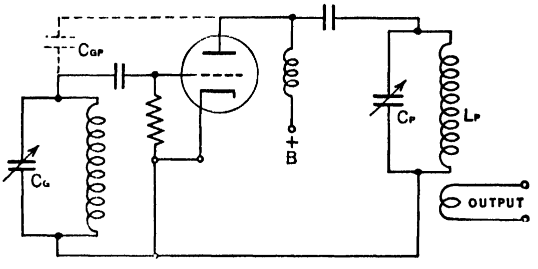


Fig. 5–32. The tuned-grid tuned-plate oscillator.

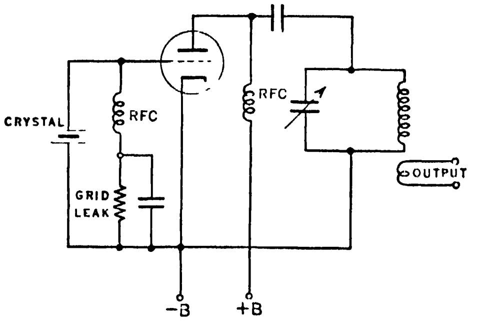


Fig. 5–33. Triode crystal oscillator, a modification of the tuned-grid, tuned-plate oscillator.

5–5f. Electron-coupled Oscillators—In the circuits described thus far, it is necessary to couple the load to the frequency-determining portion of the oscillator. Under these circumstances, any external change, such as a swinging antenna or the keying of a subsequent amplifier, may cause the frequency

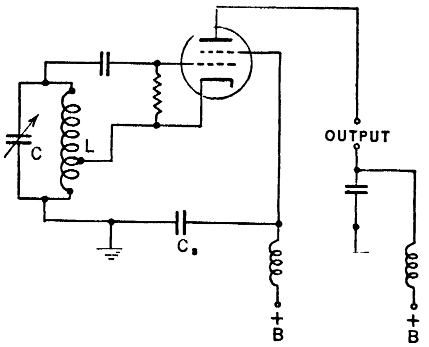


FIG. 5-34. In the electron-coupled oscillator, shown above, the screen of the tetrode acts as the plate in a Hartley oscillator arrangement. Output is taken from the regular plate circuit, usually from a tank circuit tuned either to the fundamental or a harmonic frequency. Since the screen is at r-f ground potential due to C_s, the oscillator frequency is not greatly altered by changes in the plate loading.

of the oscillator to change. Changes in the plate voltage of the following amplifier also reflect on the frequency of the oscillator to an undesirable extent. The Dow electron-coupled oscillator is comparatively free from such difficulties. The electron-coupled oscillator, illustrated in Figures 5-34, 5-35, and 5-36, makes use of a tetrode or pentode tube. The screen, control grid, and cathode form the three elements of a triode oscillator. The conventional oscillator circuit is modified by grounding the screen (which corresponds to the plate of the oscillator) through a by-pass condenser. This has the effect of shielding the plate of the tube from the inner elements. Thus the plate has no connection with, and is shielded from, the elements which generate the oscillations. The electrons which pass through the screen flow in pulses determined by the oscillations in the inner elements. This pulsating current develops power in the plate circuit load. Thus the only coupling between the oscillator and the load is the electron stream which escapes through the screen; from this fact is obtained the name "electron coupling." This coupling is one-way so that plate circuit conditions have little effect upon the frequency. To make full use of this effect, the circuit components must be carefully shielded and the tube's screening action must be complete. In addition to the frequency stability obtained by the elimination of coupling between oscillator and load, two other valuable advantages exist: (1) By properly proportioning the voltages on the screen (inner plate) and plate, the frequency may be made independent of small changes in the supply voltage. The proportion may be maintained by supplying the screen from a voltage divider, thus changing both voltages in proportion if the supply voltage shifts. (2) Substantial output can be obtained at harmonics of the oscillator frequency.

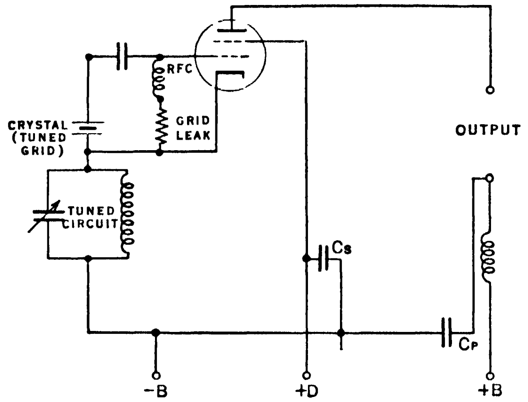


FIG. 5-36. The Tri-tet oscillator, a crystal controlled form of the Dow electron-coupled oscillator circuit. The cathode tank circuit is tuned to about 125 percent of the crystal frequency; the plate tank (not shown) is tuned to either the crystal frequency or a multiple thereof. The lower end of the gridleak may be connected to ground instead of the cathode.

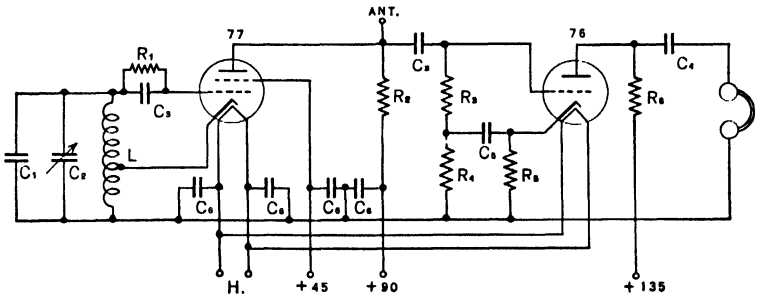


FIG. 5-35. A frequency meter employing an electron-coupled oscillator.

C_1. Band setting	R_1. 0.1 meg. ½ watt
C_2. Band spread	R_2. 0.1 meg. 1 watt
C_3. 250 $\mu\mu f$	R_3. 0.5 meg. ½ watt
C_4. 0.1 μf	R_4. 0.5 meg. ½ watt
C_5. 0.25 μf	R_5. 50,000 ohms. 1 watt
C_6. 0.05 μf	R_6. 0.1 meg. 1 watt

L. Inductance, depending upon frequency range desired.

The data given below indicate the large amounts of harmonic power that can be obtained:

TYPE 860 ELECTRON-COUPLED OSCILLATOR
(*Plate voltage 2000 volts, screen 800 volts*)

Frequency	*Power Outupt* (*watts*)	*Plate Efficiency* (%)
Fundamental	85	42
Second harmonic	62	31
Third harmonic	51	25
Fourth harmonic	32	16
Fifth harmonic	19	10

It should be noted that grounding the screen grid results in the cathode operating above ground potential at radio frequency. With filamentary-type tubes, the filament supply must be applied through r-f chokes. With certain heater-type tubes, the chokes are unnecessary, no damage resulting from the r-f voltage between heater and cathode.

The high harmonic output of the electron-coupled oscillator has made it very convenient for use as a heterodyne frequency meter. Figure 5–35 shows a suitable arrangement for this service. For amateur use, the oscillator usually operates in the 1.75-mc band. This provides harmonics sufficiently strong to permit measurements up to 28 mc. Only a single calibration is necessary, this point being transferred from band to band by merely multiplying the frequency by the correct harmonic number. Thus a beat on the setting for 1.765 mc corresponds to 3.530 in the 3.5-mc band, 7.060 in the 7-mc band, or 14.120 mc if the frequency being measured is in the 14-mc band. When checking the frequency of a transmitter, the beat is heard in the headphones connected to the detector portion of the meter. If the calibration of a receiver is to be checked, or a signal being received is to be measured, the beat is heard in the output of the receiver, and the detector associated with the frequency meter is not used.

Similar devices are supplied to the Field Inspectors of the Federal Communications Commission for frequency measurements on shipboard.

Pentodes can be used as electron-coupled oscillators if two conditions are met. First, the suppressor must be brought out to a separate pin connection and not be internally connected to the cathode. Connection of the cathode to the suppressor provides electrostatic coupling between the oscillating circuit (of which the cathode is a part) and the plate. To obtain the full benefits of the electron-coupled circuit, it is essential that the suppressor be tied to the screen, thereby assisting the shielding action. Second, certain r-f pentodes are provided with an internal shield. If this shield is connected internally to the cathode, it will provide undesired electrostatic coupling by its capacitance to the plate. The type 78 receiving pentode is connected in this way and is therefore unsuitable as an electron-coupled oscillator. The type 77 has the internal shield connected to the suppressor and is therefore satisfactory since suppressor, internal shield, and screen can be tied together and grounded to provide an effective shield between the oscillating elements and the plate.

5–5g. Dynatron Circuit—Examination of the characteristic curves of any tetrode will show that in the region where the screen voltage is about twice as high as the plate voltage (operation is normally confined to the region where the plate voltage is the higher) an increase in plate voltage will cause a reduction of plate current. Such a result would be expected if the tube's plate resistance were *negative*. If this negative resistance is connected in series with a resonant circuit, oscillations will be set up at a frequency determined solely by the circuit. A tube connected in this manner is termed a *dynatron oscillator* and differs from all other types of oscillators in that there is no feed back of energy from the plate to the grid circuit. Although dynatrons are very stable oscillators, the power that can be obtained from present-day tubes is very small. For that reason this oscillator cannot easily be used to control the frequency of a transmitter. Their main use has been as a frequency meter. Even here the dynatron has been to a large degree replaced by the electron-coupled oscillator. A typical dynatron frequency meter is shown on Figure 5–37. Note the potentiometer grid return and the cathode current meter. The error introduced by supply voltage changes is reduced by adjusting the cathode current to the same value used when the instrument was calibrated.

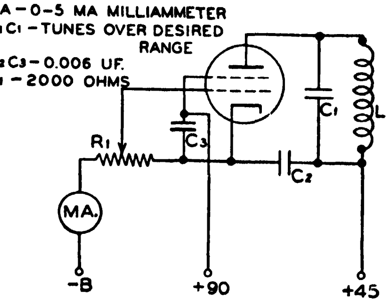


FIG. 5–37. Dynatron oscillator suitable for use as a frequency motor.

The dynatron oscillator is rich in harmonics, but not as rich as the electron-coupled circuit nor is the power output as great.

5–6. Crystal-controlled Oscillators—In a crystal-controlled oscillator, the frequency of the oscillations is determined by the piezo-electric effect of a quartz plate, which *in effect* is a tuned circuit of large inductance but very small resistance. The theory of operation of oscillating quartz belongs to the general subject of physics and will not be treated here. Briefly, when a section of quartz (properly cut from the crystal) is subjected to an electrostatic field, a mechanical strain is set up which distorts the shape. The opposite is also true—a mechanical strain in the crystal will produce a voltage difference between the two faces. The mechanical strains become large enough to produce appreciable voltages only when the crystal is vibrating (mechanically) at one of its fundamental frequencies. Every crystal has two fundamental frequencies—one depending upon the thickness and the other depending upon the surface area. The thickness vibration has the higher frequency (since crystals are cut so that the thickness is less than either the width or length) and is used exclusively for high-frequency oscillations. The surface (or contour) vibration is much lower in frequency and is used only when very low frequencies are desired.

When properly connected in a vacuum tube circuit, as for example in Figure 5–33, the impulse produced by applying the plate voltage is sufficient to start oscillations in the crystal. If the plate tuning and feedback are satisfactory, oscillations will continue at the frequency determined by the crystal. The tuning of the output circuit (of course, if the tuning is too far out the oscillations will stop), the voltages on the tube, and the power taken from the tube have only a slight effect on the frequency. When reasonable precautions are taken to keep these factors *and the temperature* constant, the frequency can be made very stable.

5–6a. Crystal Holders—The most familiar mounting for crystals consists simply of a pair of flat electrodes between which the crystal is mounted. The electrodes are in contact with the crystal faces, and a slight pressure (0.1 to 0.5 ounces) is applied to prevent any erratic motion. Another form of holder is the "airgap" type. In it a space is left between the crystal and the upper plate. This short air column loads the crystal mechanically and thereby influences, to a small degree, the frequency at which it will oscillate. By varying the airgap, the frequency can be shifted over a small range. As the airgap becomes too large, it becomes increasingly difficult to maintain oscillations and, as a consequence, the useful power output from the oscillator is reduced.

5–6b. Temperature Coefficient of Frequency—One of the most important characteristics of crystal oscillators is the frequency change due to the crystal temperature. Crystals may be cut from a parent crystal in several different ways. The principal difference between crystals cut in these different ways is the temperature coefficient of frequency, that is, how much the frequency changes for every degree change in crystal temperature.

Crystals cut with their major surfaces normal to the *Y* axis and parallel to the *X* axis and the *Z* axis are called *Y*-cut.

Apart from the relatively high temperature coefficient of frequency, Y-cut crystals have the reputation of being somewhat erratic in operation. This is explained to a certain extent by saying that the hamonics of the contour vibration sometimes fall close to the frequency vibration. As the temperature coefficients of the two modes of vibration are different, the effect varies with temperature, introducing a disturbing factor. As the temperature rises, the frequency may shift suddenly at certain points. For these reasons Y-cut crystals are not widely used.

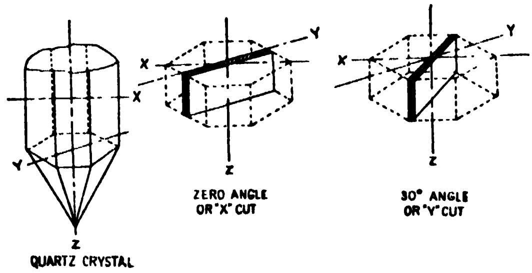


Fig. 5–38. Orientation of X- and Y-crystal cuts.

A somewhat superior crystal is obtained by cutting the plate normal to the *X* axis (electric axis) with major surfaces parallel to the *Y* and *Z* axes. These crystals are known as X-cut crystals. The temperature coefficient of frequency of these crystals is about − 22 parts per million (0.0022 percent) per degree Centigrade. The coefficient is negative, indicating that the frequency *decreases* as the temperature *rises.*

The fact that the temperature coefficients of X and Y crystals are opposite suggested that it might be possible to cut a crystal somewhere between them and secure a plate with a zero temperature coefficient, that is, frequency would not change with temperature. A number of special cuts come very close to this ideal. The AT-cut (made by Bell Telephone Laboratories) and the RCA's V-cut have temperature coefficients of ± 2 parts per million (0.0002 percent) per degree Centigrade. Such excellent performance is only possible when the manufacturing processes are held to very close limits, and consequently such crystals are higher in price. Bell Telephone Laboratories have also developed other crystals, as follows:

Crystal Cut	*Temperature Coefficient*
BT	± 2
AC	+20
BC	−20

5–6c. Frequency Changes with Temperature—Although the frequency change per degree is very small, many transmitters are likely to encounter such a wide range of temperature that the total change is considerable. Even transmitters installed in heated buildings may have a temperature range of 50° C. In winter, temporary failure of the heating plant may easily send the temperature down to 0° C (32° F). In summer, the warm weather plus the heat dissipated inside the transmitter may raise the crystal temperature as high as 60° C. (140° F).

Transmitters on shipboard, aircraft, or those located in separate unheated houses may be subject to an even greater temperature range.

Assuming 60° C, as the expected temperature range, the table below shows the frequency deviation that might result. The third column shows this deviation in percent, and the fourth column shows it in cycles at a frequency of 1500 kc.

TEMPERATURE CHANGE 60° C

Crystal Cut	Freq. Coef. Temp. Parts per Million	Deviation in Percent	Cycles at 1500 Kc
Y .	+70	0.420	6300
X	−22	0.132	1980
AT or V . .	± 2	0.012	180

5–6d. Constant Temperature Ovens—The frequency deviations resulting from large changes in temperature exceeds the tolerance allowed by the Federal Communications Commission for many classes of stations. When it does, it is necessary to prevent the temperature change by enclosing the crystal, and preferably the tuned plate circuit of the crystal tube as well, in a constant-temperature oven. This is simply a well-constructed, air-tight compartment, having heat-insulated walls, and containing a thermostat and a small heater. The thermostat is adjusted to open its contacts at a predetermined temperature. *It is necessary that this temperature be higher than the maximum outside temperature.* This is due to the fact that the apparatus provided can warm the interior if it gets too cool, but it cannot cool it if it gets too warm. If the temperature inside the compartment falls below the thermostat setting, the contacts close and current flows into the heater. This warms the compartment. When the proper temperature is reached, the contacts open and the current is shut off. As the compartment is above the outside temperature, heat is slowly lost through the walls. When the compartment has cooled again, the thermostat contacts again close and heat is again applied. Thus the inside temperature undergoes a continuous heating and cooling. The temperature range covered depends upon the sensitivity of the thermostat.

For broadcast stations, the Commission requires that the crystal temperature be maintained within 0.1° C for ordinary crystals or within 1° C if approved low temperature coefficient crystals are used. Maintaining the temperature within 0.1° requires elaborate arrangements and very sensitive thermostats. Many stations have experienced difficulty in keeping the temperature that close and have changed to low temperature coefficient crystals. The limit of 1° can be held by a comparatively simple and rugged oven. In fact, several ovens are now available which are not much larger than a mounted crystal. They are fitted with plug-in connections, and can be removed and a spare oven (including a crystal) placed in operation in a few seconds. A suitable mounting should be provided to supply power to the heater of the oven not in use, so it can be kept at the proper temperature ready for instant use.

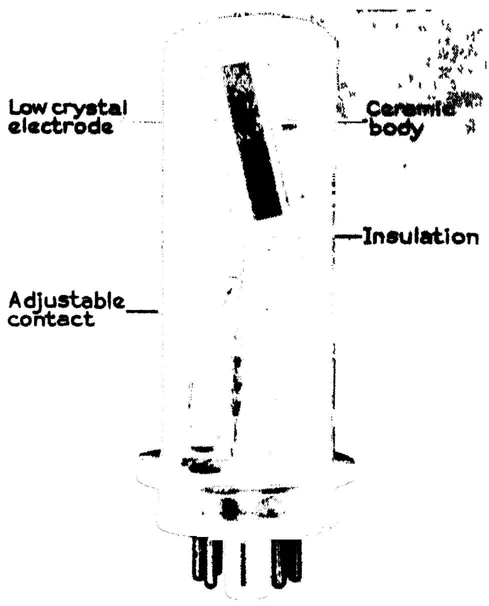


FIG. 5–39. Cut-away view of the General Electric air-gap type G-30 thermocell for standard broadcast station control.

This is a distinct improvement of the old system of having two crystals (one in use and the other for a spare) in the same oven. When this was done it was practically impossible to have both crystals exactly on frequency at the same temperature. As a result, the oven temperature was set for the one in use. The spare crystal would then be off frequency until the oven temperature could be changed. Then too, this arrangement did not provide for a failure in the oven heating circuits or thermostat.

For services other than broadcasting, the Commission does not specify any temperature limits, nor is an oven specifically required. However, compliance with the spirit of the International regulation which requires all stations to maintain frequency as accurately as the state of the art permits might be interpreted to require an oven capable of maintaining the crystal temperature to within 1° C. Such ovens are reliable, small, and can be obtained at reasonable prices. On aircraft where weight is an important factor in determining the safety of the plane, and on police cars where the interference problem is not serious because of the limited power, it is impractical to install constant-temperature ovens. In these cases, low-temperature-coefficient crystals may be employed to reduce the frequency deviations.

5–6e. Frequency Drift—As quartz crystals are not perfectly elastic (no substance is) the rapid vibrations generate heat. This raises the crystal temperature when oscillations begin, causing the familiar drift in frequency during the warm-up period. This drift cannot be completely eliminated by a constant temperature oven. When not oscillating, the crystal receives all its heat *from* the oven. Its temperature consequently will be equal to the oven temperature. When oscillating, the crystal is delivering heat *to* the oven. Its temperature consequently will be slightly above the oven temperature.

To prevent this frequency drift from being undesirably large, three things may be done:

1. The crystal oscillator may be left running all the time, thus eliminating any warm-up period.
2. The crystal oscillator may be operated at very low plate voltage, thus making the current through the crystal as well as the heating effect correspondingly low.
3. A low temperature coefficient crystal may be used.

The first suggestion is expensive (from a power consumption standpoint) and is often impractical. The second suggestion requires additional intermediate stages, thus complicating the transmitter design. The third method is by far the most practical and is recommended.

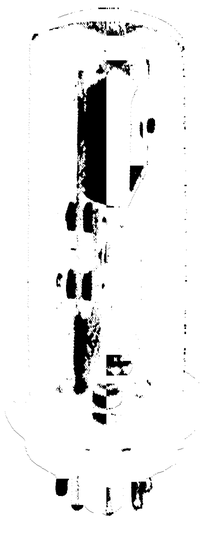


FIG. 5–40. Cut-away view of the General Electric G-31 thermocell temperature controlled crystal and mounting employed in General Electric F-M transmitters. Above a frequency of approximately 2500 kc, it is necessary to use the clamped type crystal holder as shown. The G-31 mounting is the same size as a 6L6 metal vacuum tube and mounts in a standard octal socket. The operating temperature of 60° C is reached from a cold start in 15 minutes. The temperature is held constant to better than ± 1° C. The crystal is of the low-temperature-coefficient type and may be ground to an accuracy of 0.0003; 0.0002, or 0.0001 percent, as required.

5–6f. Crystal Oscillator Circuits—There are three circuit arrangements that are in general use for crystal oscillators. The circuit most often used is shown in Figure 5–33. The circuit is the same for a triode or pentode, the only difference being the additional tube elements which are by-passed and operated at fixed voltages. This circuit is of the tuned-grid, tuned-plate type shown in Figure 5–32. The crystal takes the place of the grid tuned circuit. Feedback is obtained through the internal grid-plate capacitance of the tube. As the crystal is more efficient than any tuned circuit the feedback capacity required is very small—about 1 $\mu\mu$f usually being sufficient.

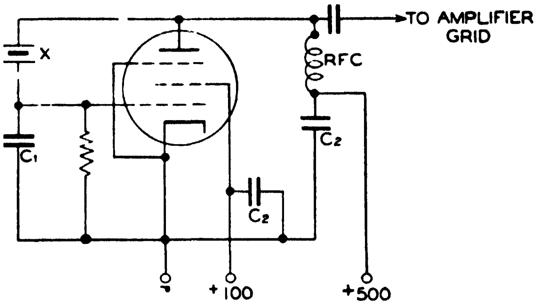


FIG. 5–41. Special crystal oscillator.

C_1—Feedback—depends upon frequency—about 0.001 μf.
C_2—By-pass—0.01 μf.

Radio-frequency pentodes (as distinguished from those intended for audio use) are so well shielded that it is usually necessary to add external grid-plate capacitance. For this reason, the less expensive audio type tubes are preferred.

The power output that can be obtained from a crystal oscillator is limited by the r-f current through the crystal. Authorities do not agree very well as to the safe current, but general opinion is that a current of 100 ma cannot be exceeded without danger of cracking the crystal. However, this amount of current is sufficient to cause considerable heating and unless low-temperature-coefficient crystals are used the frequency drift may be excessive. It is suggested that ordinary crystals be limited to about 35 ma for this reason.

When adjusting transmitters, it is suggested that a small 6.3-volt dial lamp be connected in series with the crystal. These lamps burn dimly at a current of 100 ma, show full brilliancy at 150 ma, and, it is to be hoped, burn out before the crystal is damaged. At any rate, a bright light indicates the crystal current is too high.

Figure 5–41 shows a circuit used by Western Electric in small aircraft transmitters. It is a modification of the ultraudion circuit. Condenser C_1 determines the amount of excitation, and the feedback is directly through the crystal. The internal plate-grid capacitance is not needed, and the circuit is used with a well-shielded r-f pentode. As the entire output voltage plus the grid excitation voltage appears across the crystal, it is evident that the crystal current may be quite high.

For this reason, the circuit cannot be recommended for general use. In the W. E. transmitters, the crystal current is kept low by the loading effect of the amplifier and, under these circumstances, the circuit is well suited for aircraft service. Change from day to night frequency (or from the itinerant aircraft frequency to the frequency assigned to the particular airline) is effected by simply shifting crystals, and tuning the amplifier plate circuit. There are no tuning adjustments necessary in the oscillator circuit. This makes the entire transmitter very simple, compact, and foolproof.

Figure 5–36 shows an electron-coupled form of crystal oscillator. This very useful circuit, due to J. J. Lamb, is said to consist of a triode oscillator followed by a tetrode amplifier, and thus has been named "Tri-tet," but comparison with Figures 5–34 and 5–35 will show that the same claim could be made for the original Dow circuits. The Tri-tet's main feature is its crystal control. The crystal portion of the circuit is of the usual tuned-plate, tuned-grid form. As usual the crystal tunes the grid while the "plate" is actually the screen as in the Dow circuits. Incidentally, the Dow circuits (the noncrystal circuits) are shown with Hartley circuits but also work quite excellently with the TPTG arrangement. Such an arrangement would be the same as in Figure 5–36 with the crystal replaced by a tuned circuit. Thus the improvement is entirely due to the addition of the crystal—or perhaps to the addition of electron coupling in a crystal oscillator. Nevertheless, the Tri-tet is a useful circuit, though limited to voltages at which a crystal is not endangered, while the original Dow circuit of Figure 5–34 not being crystal controlled, is not so limited, hence is often used with tubes of large size to drive directly the final amplifier of radio transmitters in services requiring a wide range of frequencies not easily met with crystals.

5–6g. Adjusting the Frequency of Crystal Controlled Oscillators—Operators of composite[7] transmitters sometimes experience difficulty in adjusting a crystal oscillator to the exact desired frequency, and some means of obtaining a small frequency change is desired. There are four methods commonly used.

1. If the thermostat is provided with an adjustment, the temperature of the oven may be shifted slightly. It takes at least 3 hours, and frequently longer, for the frequency to respond to this adjustment. Unless very carefully done, the tendency is to change the temperature too much and overshoot the mark.

2. A small capacitance of perhaps 20 $\mu\mu$f maximum may be connected across the crystal. Varying this capacitance will cause a slight shift in the frequency. This has the advantage that the frequency responds immediately. It has a serious disadvantage in that the frequency can be *lowered* but *not raised*. The capacitance must not be too large, or the crystal may lose control.

3. Detuning the crystal plate circuit in the conventional crystal oscillator circuit has a slight effect on the frequency. This is not a good way of adjusting frequency because the tank condenser should be set for minimum crystal current.

4. The use of a crystal with a variable air gap is recommended as the best way of obtaining the exact desired frequency.

After adjusting the frequency by one of the methods just described, it should remain very close to the exact value without any further adjustment for weeks at a time. If it does not, the method of frequency control is not satisfactory. It is not good engineering to make an adjustment to the frequency every day or two.

5–7. Radio-frequency Interstage Coupling—In designing interstage coupling circuits, there are three points which must be considered: (1) the desired excitation voltage must be delivered to the grid of the following amplifier; (2) there must be no coupling between the interstage circuit and any other portion of the transmitter; and (3) there must be a path from grid to cathode having low impedance at ultra-high frequencies. The first requirement is obvious but the other two require explanation. If there is any coupling between the interstage circuit and any other portion of the transmitter, r-f feedback and consequently unstable transmitter operation may result. This may manifest itself as frequency shift, bad note, key clicks, or a tendency to self-oscillation. In phone transmitters, the amount of feedback may change as a function of modulation so that no difficulty will be detected until modulation is applied. Such difficulties are very troublesome to locate and correct and should be avoided, as far as possible, by the use of suitable circuit arrangements. The third requirement is intended to reduce the tendency toward parasitic oscillations. At ultra-high frequencies, the reactance of even a few inches of wire may be sufficient to cause the generation of a parasitic oscillation.

Figure 5–42 shows the simplest type of coupling between the plate of one tube and the grid of the next amplifier. Requirement (1) must be satisfied by selecting tube types and operating voltages such that the full output voltage of the driving tube is equal to the desired excitation voltage for the following stage. With the wide variety of tubes now available, this does not present any serious difficulty.

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[7] The question of frequency adjustment of manufactured transmitters should be taken up with the manufacturers.

Requirement (2) is more difficult to satisfy. For one thing, points *A*, *B*, and *F* must be grounded by *separate short leads* to a *single ground point.* The common practice of running grounds to the chassis at the nearest point produces coupling between the ground returns of the several stages, thus introducing regeneration and instability. This is not as serious when the stage is operated as a frequency doubler, but it is always undesirable. Another requirement of (2) is that the shaded area on Figure 5–42 be kept as small as possible Any r-f field passing through this area will induce a voltage on the grid of the amplifier tube. As such a field is generated by the tank coils and wiring of the other stages, and also by the antenna, it forms a type of feedback that cannot be eliminated by neutralization. The area shaded with full lines is especially susceptible because of the voltage step-up action of the tuned circuit.

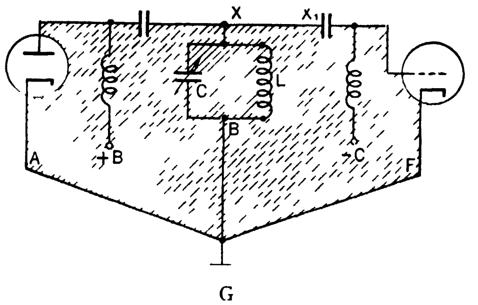

FIG. 5–42. Simplest type of interstage coupling.

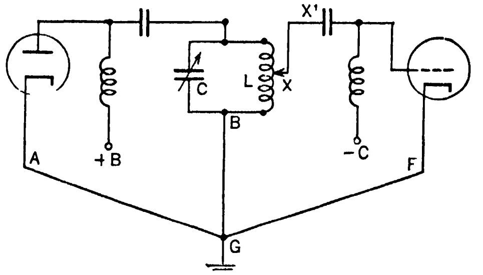

FIG. 5–43. This coupling circuit favors parasitic oscillations.

Feedback from stray fields can be reduced by employing suitable shielding between the stages. With this particular circuit, a precaution must be observed with respect to passing r-f conductors through the shield. It is natural simply to pass the lead X–X_1 through a hole in the shield. The shield then acts as the short-circuited secondary of a one-turn transformer. The lead X–X_1 is the primary. This creates a comparatively heavy r-f current in the shield around the hole and will introduce losses. The correct construction is to run ***both*** leads X–X_1 and G–F through the ***same*** hole. As the r-f current in these two wires are equal and opposite, no current should be induced in the shield, thus eliminating the losses. Requirement (3) is satisfied by making the leads X–X_1, B–G, and F–G as short as possible. (These three leads are the principal reactance between grid and cathode at ultra-high frequencies.)

Figure 5–43 shows a coupling arrangement sometimes employed when the output voltage of the driving stage is greater than desired for exciting the next stage. The excitation is varied by simply changing the position of the tap on the coil. This forms a simple means of satisfying requirement (1). Observing the precautions given for the circuit of Figure 5–42 will satisfy requirement (2), but it is on requirement (3) that the circuit fails. The path from grid to cathode cannot have the necessary low impedance at high frequencies because a portion of the preceding plate tank coil is in the circuit. The reactance of this coil increases with the frequency, producing a high grid-to-cathode impedance. This condition is favorable to ultra-high frequency parasitic oscillations and trouble may be expected. For this reason, the circuit should be avoided.

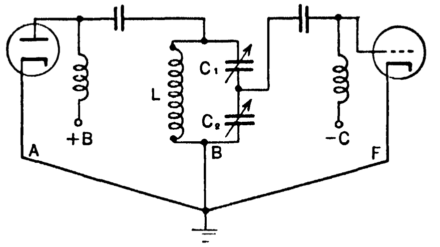

FIG. 5–44. Excitation may be controlled by dividing the tank condenser into two sections, C1 and C2 must tune L to the desired frequency.

The arrangement of Figure 5–44 overcomes the objection to the circuit of Figure 5–43 by tapping on the tank condenser instead of the tank coil. With short leads this arrangement satisfies all the requirements. The precautions with respect to grounding and shielding mentioned for the circuit of Figure 5–42 must be observed.

Figure 5–45 is a modification of the circuit of Figure 5–43. Although the inductive coupling eliminates the need for careful arrangement of

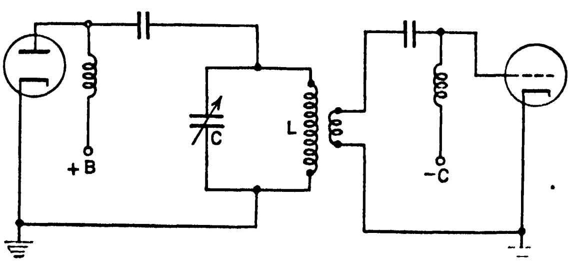

FIG. 5–45. Although this circuit is superior to Figure 5–43, it does not meet requirement No. 3.

ground leads, it does not meet requirement (3) and for this reason is not recommended.

Figures 5–46 shows a form of coupling which satisfies requirement (1) very well. Using two variable condensers, as shown, the excitation voltage can easily be adjusted to the desired value. The area R must be kept as small as possible, and the grounds must be run separately as shown. Requirement (3) can be met if the circuit elements are located close enough to permit short leads.

In the five circuits just described, the requirements can be met only when all connections are as short and direct as possible. This means that the two stages must be located very close together. This is not always possible, nor is it always desirable. Apart from mechanical considerations, the dissipation of heat requires that the tubes be amply separated and well ventilated. It has recently become popular to use short transmission lines between the various stages. This arrangement is shown in Figure 5–47. Twisted pair is most frequently used for the link which joins the stages. Such pairs have considerable losses at ultra-high frequencies, but these become small for short lengths. The characteristic impedance of such conductors ranges from 50 to 200 ohms, depending upon the dimensions of the conductors and the character of the insulation. For high power, concentric transmission line is convenient and efficient. For such short distances, a large mismatch of impedance has a negligible effect.

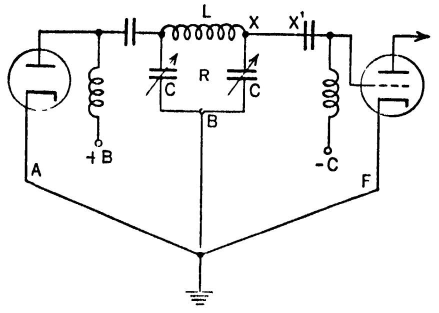

FIG. 5–46. A satisfactory interstage coupling arrangement.

Satisfactory results are secured by using a 1- or 2-turn link tightly coupled to the tank inductances. With this link coupling, proper excitation voltage can be secured by changing the position or number of turns in either coupling coil. This type of coupling lends itself to shielding very well because the transmission line can be run through a small hole in the shield with very small losses. The principal advantage is the fact that it becomes possible to keep all connections extremely short without crowding the stages together. Note that it is not necessary to run separate ground leads to the same ground point. In this circuit the ground wires do not carry r.f. and are provided merely as a safeguard. If one side of the transmission line is grounded, the line acts as an effective electrostatic shield between the stages. This greatly reduces the transfer of energy at frequencies other than the fundamental which is highly beneficial, as it prevents the transfer of parasitic energy from stage to stage.[8] This improves the stability of the transmitter to such an extent that many transmitters employ this type of coupling between each stage even where the transmission lines are only a few inches in length.

5–8. R-f Amplifier Output Circuits—In one sense there is no distinction between interstage and output coupling devices, since both are intended to transfer the r-f output of a vacuum tube to its load. For the interstage device the load consists of the grid circuit of the next tube, the stray losses of the circuit, and in some cases a resistor connected to the interstage coupling device for the purpose of stabilizing the impedance of the load. For the output device, the load consists, usually, of an antenna. The interstage coupling circuits of a transmitter have a relatively simple task to perform—to drive the following grid hard enough so that a certain plate current shall appear. Adjustment which will produce that plate current is usually satisfactory;

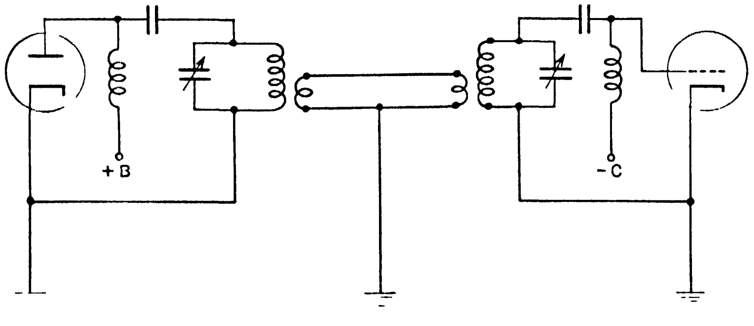

FIG. 5–47. "Link" coupling permits short leads without crowding the stages. The link may be any length. Ordinary twisted pair may be used for short distances with low power.

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[8] Although this reduces the harmonic in the excitation, it does not have any appreciable effect on the harmonics in the final amplifier output. R-f harmonics that are radiated are generated in the final amplifier and their reduction in previous stages will have no effect.

the nature of the load is well known, and ample power for feeding it is readily provided.

The following pages consider the final-stage output device which feeds the antenna. Considerable discussion is justified by the importance of this particular coupling which is called upon to make proper use of the relatively large power produced by the final-stage tubes, by which is meant a suitable suppression of harmonics and a transfer of the major portion of the output to a load which is never exactly predictable—the antenna. These requirements result in a coupling device between the final tubes and the antenna which has larger adjustment range than is necessary in the intertube couplings; frequently the adjustments are more numerous as well.

5–8a. The L/C Ratio of the Plate Tank Circuit—Before going to the unavoidable mathematical treatment of the tuned plate circuit in the following pages, it is useful to consider the effect of changing the relative proportions of the coil and capacitance.

It is, of course, possible to tune to the same frequency with a large coil and small condenser, or a small coil and large condenser. At the same time it seems that there must be an optimum combination. This is true, but the same combination is not best for receiving and for transmitting, since the requirements are different.

In the case of the receiver we are usually working with small voltages; even at the last stage of the i-f amplifier 10 volts make a large signal. Thus the problem is to get all possible amplification consistent with the limitations of selectivity and noise. Accordingly the interstage transformers are proportioned to secure high voltage gain. Thus, in a tunable r-f stage working (for the moment) at 1000 kc a voltage gain of 100 times or more is expected, even though the necessity of tuning over a considerable range compels the use of a variable tuning condenser whose capacitance is higher than would be chosen for a *fixed* 1000-kc amplifier. Thus the idea here is to use as small a condenser and as large a coil as is reasonably convenient. In the fixed-frequency i-f amplifier of superheterodynes this idea is carried quite far, with high gains resulting.

In the case of the transmitter the r-f stages are working under Class B and Class C conditions. In general, the voltage gain of Class B and C stages is smaller than for Class A stages, whereas the grid-input power and the plate-current distortion are larger. Thus the interstage device has a different task than in Class A r-f amplifiers. An actual *load* is being fed and there is need of correcting the *plate current distortion* of the driving tube. Consideration of the effects in detail are discussed later in this chapter, but for the moment it is helpful to consider qualitatively the consequence of changing the proportions of L and C in such Class C and Class B r-f work. Recalling from earlier paragraphs the intermittent (pulsating) character of the plate current of a single-sided Class B stage, and the deformed current wave of the Class C stage (even when used in push-pull), it is clear that one task of the tank circuit is to convert such deformed current waves into sine waves, in particular to reduce their harmonic content. This can best be done by a tank circuit with a large C and small L, the opposite of the receiver requirement. Several explanations can be offered, one of the simplest being that a large C and small L offer low impedance at nonresonant frequencies and therefore greatly reduce the harmonics. At resonance the impedance is practically as high as it would be with a larger coil and smaller condenser. This is a sketchy presentation and to be regarded as merely preliminary to the more exact treatment following.

5–8b. "High Efficiency" Tuned Plate Circuits for Class C Stages—Considerable discussion is heard from time to time about tank circuits capable of producing very high plate-circuit efficiency. Such tank circuits use very high inductance and very small capacitance and therefore present to the tube a high-impedance load at both the operating frequency and the harmonic frequencies. In consequence the amplification at the harmonics is increased and the wave form distorted. The output power is lowered, but the input requirements decrease even more—in other words, the plate efficiency increases. If the plate voltage, grid bias, and grid excitation are then increased until the plate dissipation is once more normal, it will be found that the output power is materially above normal. The disadvantages of this type of operation are the exceptional d-c voltages required, the probable need of an added driver stage to supply the high excitation, the high r-f voltages in the tank circuit, and the inability of such high L tank circuits to correct the distortion—in fact this inability is the basis of the high efficiency. Additional circuits must therefore be provided to suppress harmonics. Such a high-efficiency stage is ordinarily not suited to modulation. The very high plate-current peaks are injurious to the filaments of some tube types. In general, efficiencies in the 75–85 percent region should be attempted only after discussion with the tube manufacturer and thorough consideration of all factors. This type of operation is not considered in the following paragraphs.

5–8c. Theory of Tank Circuit Operation—Harmonics are removed from the output of a Class B or C r-f amplifier by the tank circuit in much the same manner that a mechanical flywheel smooths the rotation of a shaft. During that portion of the cycle that the tube is delivering more power than the load is taking, the spare power is stored in the tank circuit; during other portions of the cycle the tube is not delivering as much power as the load is taking, hence the tank circuit is giving up its stored energy. Except for this action of the tank circuit, the load (which is the input of the following amplifier or the antenna, as the case may be) would receive all of the harmonics present in the tube's output. Thus, the effect of the tank circuit may be stated in terms of the reduction of harmonics originally present.

The harmonics present in a tube's output current are not definite or predictable. In a single-sided Class B r-f amplifier the output consists of plate current pulses having the shape of the positive halves of a sine-wave cycle—during low modulation. For this shape the harmonic components are found easily enough. In Class C amplifiers the plate current wave form is complex and the proportions vary with changes of excitation and loading. It is good engineering practice to consider the worst condition normally encountered. In normal amplifiers the second harmonic (double frequency) current does not exceed 70 percent of the fundamental and the third harmonic (triple frequency) current does not exceed 30 percent. Higher harmonics, as a rule, need not be considered because a design which will reduce both the second and third harmonics will reduce the higher ones to an even greater degree.

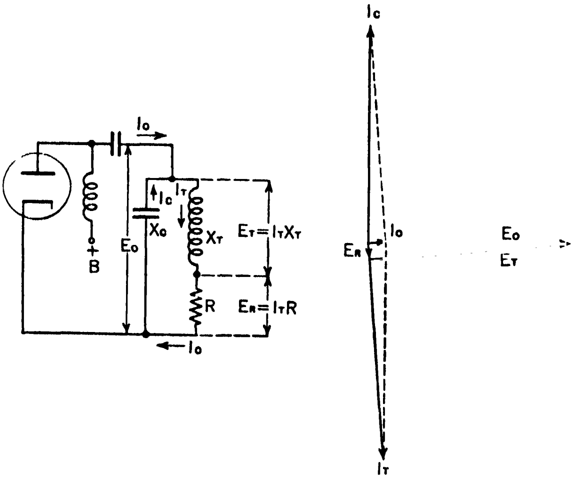

Fig. 5–48. Simple tank circuit. Values shown are: Eo, 970 volts; Io, 0.829 amp; Ic, 10.55 amp; Et, 968 volts; Er, 75.1 volts; Xc, 92 ohms; Xt, 91.8 ohms; R, 7.19 ohms.

The simplest type of tuned tank circuit is shown in Figure 5–48. In this circuit the load has been shown as a simple resistance in series with the coil. This is the simplest case. An antenna could have been shown as the load, but this would introduce complications that can be better shown separately. The tuning adjustments have also been omitted, though it is to be understood that the circuit has been tuned to resonance with the frequency which is being supplied to the system by means of the tube's grid. The resonant adjustment is found in the usual way by tuning for the minimum plate current. When this adjustment has been made, the following conditions will be found to exist:

1. The a-c plate current is in phase with the a-c plate voltage, that is, they pass through zero at the same instant.
2. The a-c current through the tank coil *lags* almost 90 degrees, that is, it is almost ¼ cycle *late* as compared to the a-c plate current and voltage.
3. The a-c current through the tank condenser *leads* almost 90°, that is, it is about ¼ cycle *ahead* as compared to the a-c plate current and voltage.
4. From 2 and 3 it follows that the condenser current and coil current differ by 180°, that is, they are ½ cycle apart as to time (phase). At the instant the current through the coil is maximum downward, it is maximum upward through the condenser—in other words, the current circulates *around* this closed tuned circuit, while at the same instant the a-c plate current flows through both coil and condenser in the *same* direction. Thus the condenser and coil current are not precisely the same, though nearly so because the circulating current is the larger.
5. There is presented to the tube a load which *for the resonance frequency only*, is a pure resistance much higher (in ohms) than the actual load R.

The value of the transformed resistance depends upon the tank reactances and is *approximately* given by:

(1) Load in ohms presented to tube

$$= \frac{X_L^2}{\text{actual load in ohms}}$$

where the actual load is R in the diagram (and is so located), while X_L is the inductive reactance of the tank coil at the working frequency. (It is not felt that the derivation of the equation is of present interest. It is correct where the coil reactance is materially larger than R.)

Thus by choosing a suitable coil the value of R may be transformed in a manner suitable to the tube to be used.

Example: What tank constants are necessary to convert an actual 7.19-ohm load into 1170 ohms as seen by the tube?

Putting the known facts into the equation, we have:

$$1170 = \frac{X_L^2}{7.19},$$

$$X_L^2 = (1170)(7.19)$$

$$X_L = 91.8 \text{ ohms}$$

And since the circuit is resonant, $X_c = X_L$.

It then remains to calculate the inductance which has a reactance of 91.8 ohms at the working frequency to provide such an inductance and to place across it a condenser capable of tuning it to resonance. Sometimes it is more practical to calculate the capacitance which, at the working frequency, offers the necessary reactance, the same number of ohms just found for the coil. Then capacitance may be set at that value and a coil picked by trial to secure resonance at the desired frequency. The coil is then of the correct size but, when connected into a transmitter, the tuning capacitance will be slightly smaller than calculated because it is shunted by various circuit and wiring capacitances.

5–8d. Reduction of Harmonics by the Tank Circuit—Assume that the output of the tube contains the largest harmonic distortion considered above, that is, a 70 percent second harmonic and 30 percent third harmonic. The tube's a-c output current is 0.829 amp, and the tank condenser reactance is once more assumed to be 92 ohms at the fundamental frequency, the load being 7.19 ohms as before.

From equation (1) the tube's load at the working frequency was found to be 1170 ohms. The voltage across this is 1170 ohms × 0.829 amp = 970 volts.

The tube's load at the second harmonic is much lower than at the fundamental, since resonance is far removed. However, resonance is not so far removed as to disappear altogether; hence instead of assuming that the load at second and third harmonics is 0.5 and 0.33 of the fundamental X_c, it is necessary to assume values near 0.66 and 0.37. Thus at the second harmonic the load may be (0.66) (91.8 ohms) = 61 ohms, and since the second harmonic current is assumed to be 70 percent of the fundamental current, the voltage across the tank is:

$$0.7(0.829) \text{ amp} \times 61 \text{ ohms} = 35.4 \text{ volts}$$

But 35.4 volts is *not* 70 percent of 970—it is only 2.74 percent. Thus the second harmonic *voltage* has been much reduced as compared to the component of second harmonic current which was present in the plate current. Moreover this is the voltage across the tank circuit, only a portion of which arrives at the load, the rest being expended upon the inductive reactance of the coil, the final effect being that:

$$\frac{\text{Load current for a harmonic}}{\text{Load current at fundamental}} = \frac{k}{(n^2 - 1)(X_L/R)}$$

where k is 0.7 for the second harmonic, or 0.3 for the third harmonic, n is the number of the harmonic (that is either 2 or 3), X_L is again the reactance of the tank coil at the working frequency, and R is once more the actual load ohms connected into the circuit in the manner of Figures 5–48 and 5–49 whereas "load current for a harmonic" means the harmonic current through the actual load R. The values of the harmonic currents found when using the factors 0.7 and 0.3 as suggested are the largest which need be apprehended in normal Class C stages. The "high efficiency" condition of Section 5–8b is excepted.

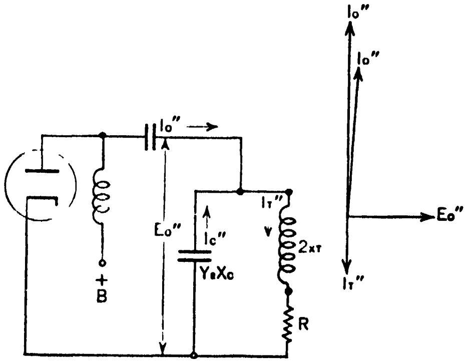

Fig. 5–49. Simple tank circuit at second harmonic. Values shown are: Eo, 35.5 volts; Io, 0.579 amp; It, 0.193 amp; Ic, 0.772 amp; Et, 35.4 volts; Er, 1.39 volts; ½Xc, 46 ohms; 2Xt, 183.6 ohms; R, 7.19 ohms.

5–8e. Significance of the Tank "K"—The equations of the last few sections may be rewritten in another form on the basis of the circulating tank current. The advantage of this rewriting is that the tank current is easily measured as are the load current and resistance; hence the harmonic reductions are more easily approximated on that basis. Figures 5–48 and 5–49 do not apply well here since they show the load resistance directly in the tank circuit so that the load current and circulating current are necessarily the same. However in a case like that of Figure 5–50 it is possible to measure the tank current and the antenna current independently, also to measure the antenna's resistance by the usual means.

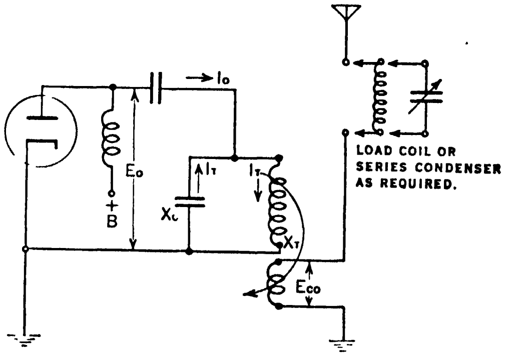

Fig. 5–50. Inductive coupling.

The antenna power is $I_a{}^2R_a$ where I_a and R_a are the antenna's current and resistance (measured at the same point). This, then, is the power delivered by the transmitter, that is, the power taken from the tank circuit. The current circulating in the tank circuit is already measured and the voltage across it may be found either by measurement (with an rms device) or by calculation (tank current times the reactance of the coil). Then the circulating volt-amperes value of the tank circuit is the simple product of the tank current and tank voltage. This circulating volt-ampere product will be found to increase as the condenser is made larger and the coil made smaller, resonance being maintained. If this is stated mathematically, we have:

$$VA/W = (E_t I_t)/(I_a^2 R_a)$$

where VA is the circulating volt-amperes of the tank circuit, W is the output in watts, and the subscripts t and a indicate tank and antenna respectively, with E, I, and R having the usual meanings.

The ratio of VA/W is sometimes called the K of the tank circuit, though clearly not a property of the tank alone, but of the tank *and* load. Using this K, the equations already given become:

$$\text{Ohms presented to tube} = (R)(K^2 + 1)$$

where R is the actual load and K is (as just explained) the ratio of the tank's circulating volt-amperes to the output watts,[9] and:

$$\frac{\text{current for a harmonic}}{\text{current at the fundamental}} = \frac{k}{K(n^2 - 1)}$$

where k is as before 0.7 for the second harmonic and 0.3 for the third, n is the number of the harmonic (either 2 or 3) and K is the "tank K" as explained above. The currents are those through the inductive leg of the tank.

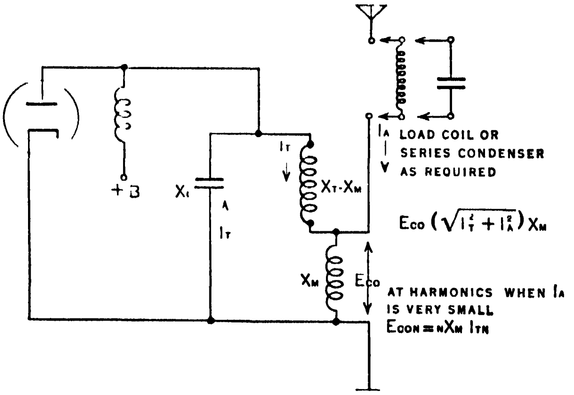
+B
X₁
I_T
I_T
X_T-X_M
X_M
E_CO
I_A
LOAD COIL OR SERIES CONDENSER AS REQUIRED
E_CO (√(I_T² + I_A²)) X_M
AT HARMONICS WHEN I_A IS VERY SMALL
E_CON = nX_M I_TN

Fig. 5–51. Direct antenna coupling.

5–8f. Practical Antenna Coupling Circuits—In the simple tank circuits of Figures 5–48 and 5–49 it was not possible to change the ratio of "resistance transformation" without at the same time changing the ratio of harmonic suppression since the only adjustment (except resonance tuning) was an outright change in the L/C ratio. A degree of independence can be attained by using the tank coil as an autotransformer by connecting the load across some turns of the coil as in Figure 5–51 (rather than in series therewith). All the advantages, however, of such a circuit, and others as well, are possible by using the familiar circuit of Figure 5–50. This circuit permits changes of coupling to be made by mere mechanical movement of the coil at the antenna base, or by removing turns from this coil and restoring the antenna to resonance by adjustment of the loading devices shown at its upper part. In either case there is, of course, a reaction upon the tuned tank circuit, requiring retuning at that point. Figure 5–51 is equivalent to Figure 5–50 if the coil X_M of Figure 5–51 is thought of as the *mutual* inductance of Figure 5–50. It is convenient to consider the circuit in this way in comparing its performance with that of the capacitive coupling system shown in Figure 5–52, formerly in quite extensive commercial use in the simple form here given, though now generally superseded in the same service by systems employing transmission lines.

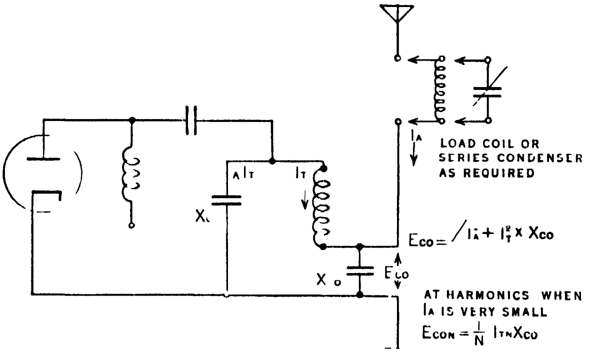
I_T
I_T
X₁
I_A
LOAD COIL OR SERIES CONDENSER AS REQUIRED
E_CO = √(I_A² + I_T²) × X_CO
X_CO
E_CO
AT HARMONICS WHEN I_A IS VERY SMALL
E_CON = 1/N I_TN X_CO

Fig. 5–52. Capacitive coupling to antenna.

In the capacitive coupling system (Figure 5–52) the circuit element common to the antenna and the tank circuit is the coupling condenser's reactance X_{co}. The coupling can be varied by varying this capacitance which is always larger than the tuning condenser in series with it. At low and medium frequencies the coupling capacitance required is large, and mica rather than air condensers are usually used. Since the voltage which feeds the antenna is developed by the passage of the tank current through the coupling condenser, and since this reactance is smaller for the harmonic frequencies, it follows that harmonic reduction is effected by this coupling. On the contrary, in the inductive coupling system of Figure 5–50, the antenna voltage is developed across an inductive reactance, and such reactances *rise* with increasing frequency, hence the tendency is to transfer them with an effectiveness increasing with frequency. Therefore, the harmonic reducing effect of the capacitive coupled arrangment is n^2 as compared with inductive coupling, where n is the harmonic number. Therefore, the capacitive coupled circuit is 4 times as effective for second harmonic reduction and 9 times as effective for the third harmonic.

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[9] If the tank losses can be neglected, it is sometimes more convenient to consider the output watts at the tube, the tube's rms alternating plate current being also easily measured.

5–8g. Effect of the Antenna upon Harmonic Radiation—It is possible for the antenna to effect some harmonic reduction but it is exceedingly unsafe to rely upon this effect to any great extent. A grounded vertical antenna ⅙ wave length high, loaded at the base with inductance so that its electrical wave length becomes ¼ wave length in the usual Marconi manner, may be expected to effect reduction of the second harmonic but will be quite effective in radiating any third harmonic power that reaches the antenna. Whenever the antenna is more than ⅙ wave length long, it is recommended that the harmonic reduction effected in the transmitter be made very large.

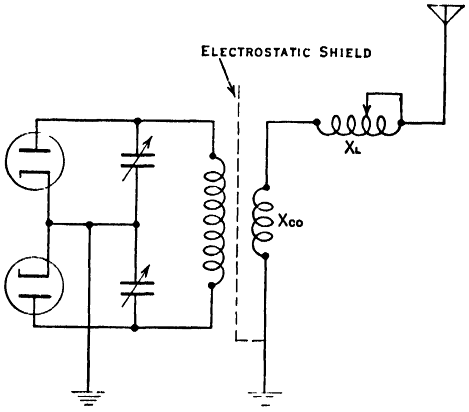

Fig. 5–53. Push-pull circuit inductively coupled to antenna with electrostatic shield to suppress radiation of harmonics.

5–8h. Harmonic Cancellation of Push-pull Amplifiers—When tubes are connected in push-pull, even harmonics do not appear at the output because they flow in opposite directions through the two sections of the tank inductance, causing their magnetic fields to oppose. If the load circuit is coupled equally to each half, there will be no even harmonic voltage set up in the load circuit. In this case the harmonic reduction should be based upon the third harmonic. For a given limit of harmonic output, this will require less K of the tank since the third harmonic is reduced more easily than the second. This reduces the tank currents, permits less expensive components to be used, and reduces the losses in the tank circuit. A suitable push-pull circuit is shown in Figure 5–53. Note that the tank condenser is divided, the center tap being connected back to the cathode circuit. This is necessary to provide a low-impedance return path for the harmonic components of the tube output currents. If such a path is not provided, considerable harmonic voltages may appear between the tank circuit and ground.

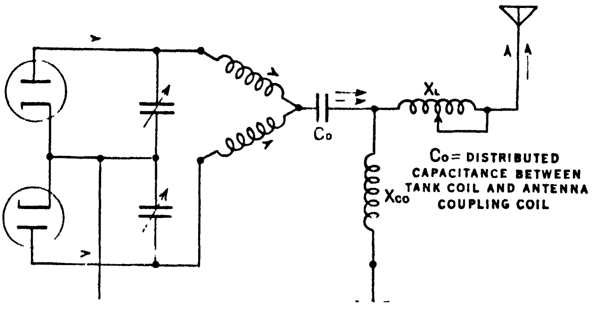
A
XL
Co
Co= DISTRIBUTED CAPACITANCE BETWEEN TANK COIL AND ANTENNA COUPLING COIL
Xco

Fig. 5–54. Stray capacitance between tank and antenna circuit provides low impedance path for harmonics. See text.

Many operators have been surprised to find a strong second harmonic being radiated from their push-pull amplifier. Although the two halves of the tank inductance will cancel even harmonics, the stray capacitance between tank and antenna circuit provides an easy path for the harmonic currents to pass into the antenna. As far as this capacitive transfer is concerned, the two tubes are in parallel and feed the antenna as shown in Figure 5–54. This is a form of direct coupling, and unless the reactance X_{co} is very small, the coupling is fairly tight. In fact, at high frequencies it is practically impossible to make X_{co} small, because a wire only a few feet long has appreciable reactance. For example, at 7000 kc a thin wire may have as much as 25 ohms reactance per foot.

Push-pull amplifiers should always have an electrostatic shield between the tank coil and the antenna coil. This will entirely prevent the transfer of even harmonics and the radiation of such harmonics will be solely determined by the accuracy with which the two tubes are balanced (plus, of course, the harmonic reducing effect of the tank circuit). In existing transmitters where it may be

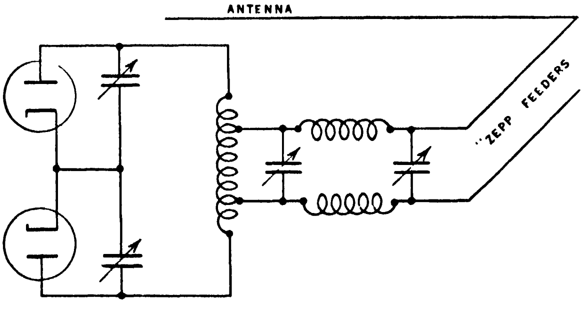

Fig. 5–55. Direct coupling of transmission line is subject to harmonic radiation.

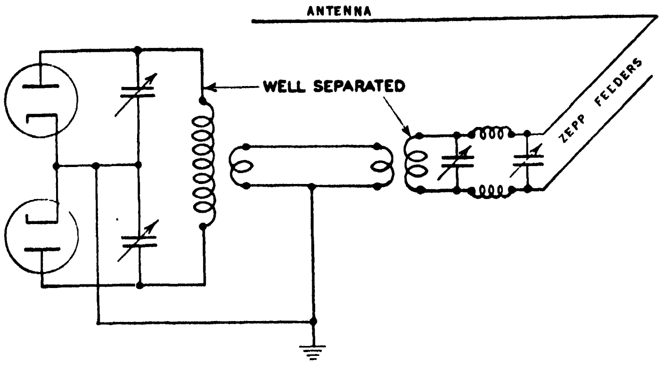

Fig. 5–56. Link coupling to transmission line is effective in the suppression of harmonics.

difficult to install a shield, improvement can sometimes be effected by using link coupling from the tank to antenna circuit. By grounding one side of the link, it can be made to function as a shield itself. The tank and antenna coils should be separated or well shielded, or the isolating effect of the link will be reduced.

The circuit of Figure 5–55 has been in wide use but is particularly poor from a harmonic radiation standpoint. The two transmission wires act much like a two-wire antenna directly coupled to the plates of two tubes in parallel. As there is no voltage difference between the wires (for even harmonics), the condensers across the line have no harmonic shunting effect. When modified to the circuit of Figure 5–56, these difficulties vanish and the circuit becomes highly effective. However, it is in all cases advisable to make a test of the field strength at the second and third harmonics, and to adjust the antenna coupling device carefully in order to minimize these harmonics.

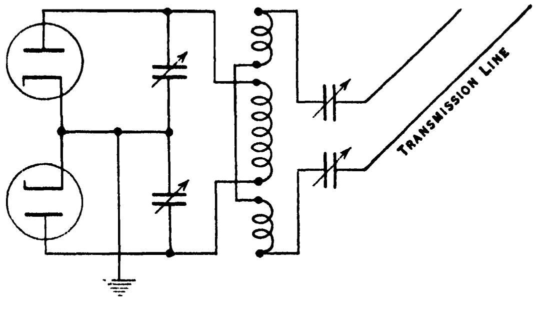

Fig. 5–57. This circuit, which is frequently employed, will radiate strong harmonics.

Figure 5–57 is another circuit which is poor from the standpoint of harmonic radiation. Here the electrostatic capacitance between the antenna coils and the tank inductance is sufficient to provide excellent coupling for the even harmonics. Placing the antenna coil over the center of the tank inductance makes no improvement because the entire tank inductance is at the same even harmonic voltage. This circuit can be vastly improved by the addition of a shield, or the use of link coupling with one side of the link grounded. While this discussion has been limited to even harmonics, the same effect which passes the even harmonics will prevent the proper reduction of the odd harmonics as well.

5–8i. Standards of Harmonic Reduction—Before the equations of previous sections can be applied to the design of output circuits, how much reduction of harmonics is *necessary* must be determined. The general law on this subject is found in the 1932 Madrid Treaty * which requires all stations to reduce their harmonics as much as the state of the art permits. As the state of the art permits almost any conceivable degree of reduction, strict application of this requirement would be unreasonable. As a practical matter, this is interpreted to require well-designed output circuits, in keeping with the power employed and the class of service. The I.R.E. standardization committee suggests that for broadcast service the harmonic field strength be limited to 0.02 percent of the fundamental field strength. This value is consistent with good engineering practice.

5–8j. Value of K Required to Reduce Harmonics to the Desired Degree—Although the values of *K* can be easily computed by using the equations developed on the preceding pages, it is more convenient to refer to the curves of Figure 5–58, which have been worked out from these equations. For single-ended amplifiers, the curves marked "second harmonic" should be used because this harmonic will be the strongest. For push-pull amplifiers *using an effective electrostatic shield between tank coil and antenna* the second harmonic will not be transferred, and the "third harmonic" curves should be used. Notice particularly that separate curves are shown for inductive coupling and for

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* Definite recommendations were made at the Atlantic City Conferences in 1947 that the harmonic content for transmissions in the frequency range from 10 to 30,000 kc be at least 40 db below the power of the fundamental and in no case shall it be greater than 200 milliwatts.

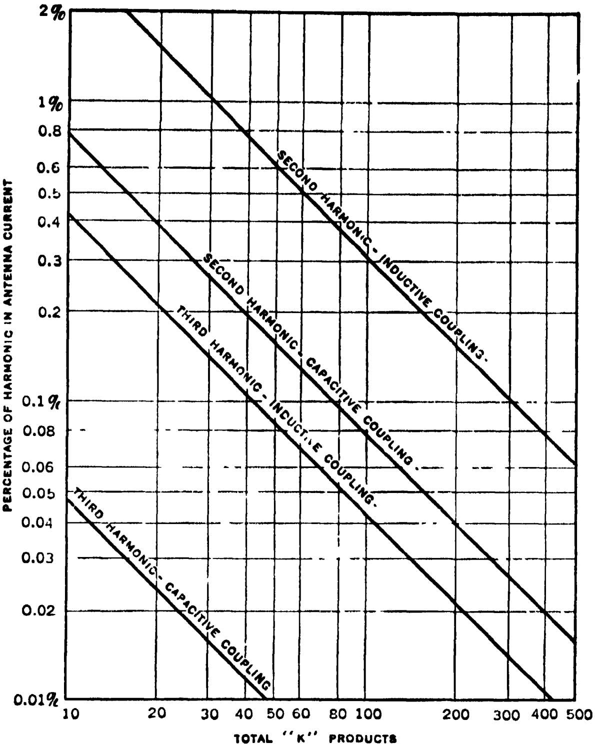

FIG. 5–58. Relationship between K and harmonic current in the antenna.

capacitive coupling. In circuits which use both inductive and capacitive coupling, the capacitive curve is used.

5–8k. Suitable Circuits for Harmonic Reduction—Although the derivation showed that the K of a tank circuit could be made as high as desired by simply increasing the tank capacitance, a practical limit is soon reached because of the heavy tank currents that are produced with high K. This makes very expensive construction necessary and increases the tank losses. In fact, with K values of 200 to 300 the tank losses are so great that very little power is left to deliver to the load. For this reason, *good engineering requires that tank circuits should have a K of not more than 20* (except for oscillators where frequency stability is desired instead of large output). Inspection of the curves on Figure 5–58 show that the recommended harmonic reduction to 0.02 percent of the fundamental requires K values far in excess of 20. This necessitates cascaded tank or other tuned circuits. The necessary values are then easily obtained without exceeding 20 in any one circuit because the resulting K is equal to the product of the individual K's. Thus a K of 120 can be obtained by a tank K of 20 and an antenna K of 6. High-power transmitters require excessively large values of K if a single-ended amplifier is used. It is therefore rec-

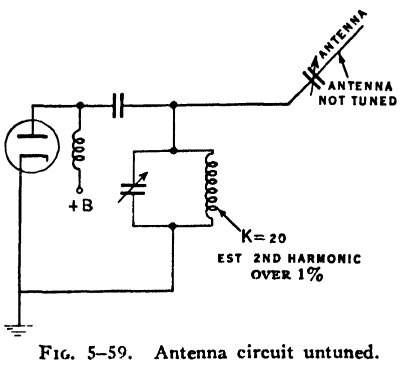

FIG. 5–59. Antenna circuit untuned.

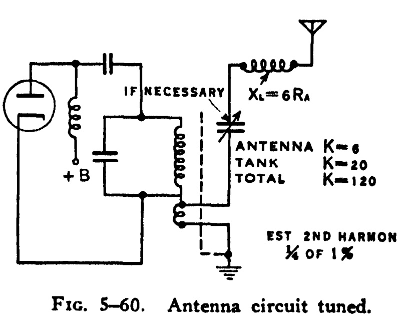

FIG. 5–60. Antenna circuit tuned.

ommended as a design rule that *the final amplifier of any high-power transmitter should be push-pull.*

Several conventional circuits are shown on the following pages to illustrate how various circuit arrangements reduce harmonics. The simplest practical circuit is that of Figure 5–59. Here the antenna is not tuned. The series condenser merely adds reactance to the antenna so that proper loading results when it is connected, as shown, directly to the plate of the tube. With this arrangement the antenna does not contribute any harmonic reduction. In fact, with certain lengths of antenna one or more harmonics may be considerably increased. Neglecting the unpredictable effect of the antenna, the second harmonic current will be greater than one percent of the fundamental even with the highest practical *K* (20) in the tank circuit. This circuit should be used only with extremely low-power transmitters (10 watts or less).

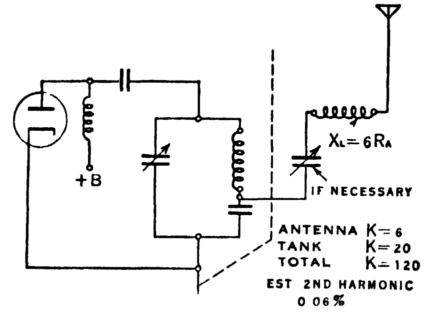

FIG. 5–61. Capacitive coupled circuit.

The arrangement shown in Figure 5–60 is a considerable improvement. By tuning the antenna an additional *K* of at least 6 can be obtained. The antenna loading inductance is an essential portion of the circuit (even if the antenna is large enough to resonate without it) and must be shielded from the tank circuit. Using a loading coil whose reactance is 6 times the antenna resistance and a tank circuit with a *K* of 20, the second harmonic should be only 0.26 percent. Unlike Figure 5–59, this will not be much disturbed by an unfavorable antenna length if the shielding is satisfactory. The coupling coil should be placed at the grounded end of the tank inductance to avoid the necessity of an electrostatic shield between these two coils.

Figure 5–61 shows a simple capacitively coupled circuit. This is not suitable for high-frequency use because of the difficulty in obtaining a low reactance ground connection. At low frequencies, the circuit performs very well, and with the constants shown the second harmonic should be reduced to 0.06 percent. This is satisfactory for transmitters of moderate power, especially if the final amplifier is operating in Class B and therefore contains only small harmonic components in its plate current. However, the advantages of this circuit cannot be realized unless the tuning is carefully done. As this tuning is rather intricate, this circuit cannot be recommended for composite transmitters unless the operators are thoroughly familiar with the process.

Figure 5–62 shows a simple push-pull circuit. *It is essential that an electrostatic shield be placed between the tank coil and the antenna circuit.* Without such a shield, the second harmonic will be quite strong. With an effective shield the second harmonic will not appear, and the third harmonic should be below 0.035 percent. This is not far in excess of the I.R.E. recommendation. This circuit has the advantage of being fairly easy to tune. The coupling is adjusted by varying the number of turns in the coupling coil. This is necessary because it is usually impractical to vary the separation when the coils are arranged for satisfactory shielding. This is, of course, a mechanical problem and any method of varying the mutual inductance will be satisfactory provided it does not introduce any direct capacitance between the two windings.

Figure 5–63 is an adaptation of capacitive coupling especially suitable for high-frequency transmitters. In this particular arrangement the antenna

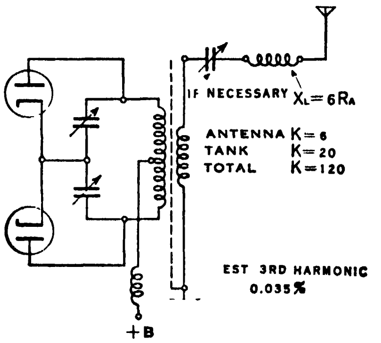

FIG. 5–62. Push-pull circuit with inductive coupling to tuned antenna circuit and electrostatic shield between coils to suppress harmonics.

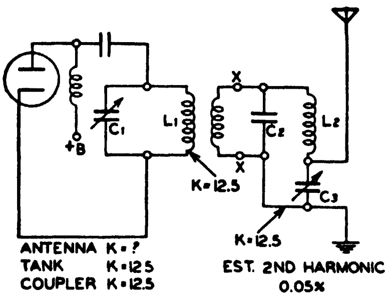

FIG. 5–63. Combined inductive and capacitive coupling to antenna circuit.

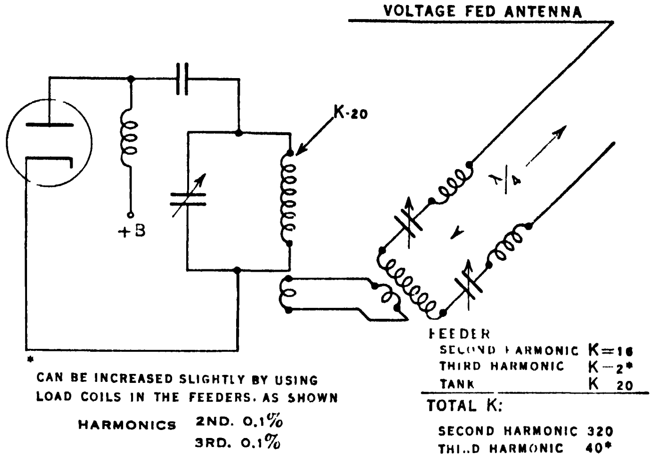

FIG. 5–64. Link coupling to transmission line. Voltage- or end-fed antenna.

is not tuned, the harmonic reduction being effected by two tank circuits in cascade. With the constants shown, the second harmonic should be about 0.05 percent. With a K of 20 in each circuit, the second harmonic could be reduced to 0.02 percent but this is usually not necessary at moderate powers. This circuit has three disadvantages: (1) the circuits must be carefully resonated; (2) care must be taken to prevent stray capacitance between the tank coil and the antenna circuit; and (3) as the antenna is not tuned, it may resonate at some harmonic and increase it. Proper K in the second circuit (the coupling circuit) is assured by making C_2 four times as large as C_1, and having a 2 to 1 ratio between tank turns and coupling coil turns. As C_2 is the final resonating adjustment, L_2 must be adjusted by trial until resonance and proper loading are obtained with the proper capacitance at C_2. The procedure is as follows: Disconnect the coupling coil at the points marked X on Figure 5–63. Now resonate the tank condenser, C_1, tuning for minimum plate current. After this, do not make any further adjustment to C_1. Reconnect the coupling coil and set C_3 at maximum capacity. Tune C_2 for resonance—minimum plate current. If the minimum plate current is too low (loading too light), decrease C_3 and resonate with C_2. If C_2 resonates with too much capacitance, increase L_2; if C_2 resonates with too little capacitance, decrease L_2. Adjust C_3 and L_2 until proper loading is secured with C_2 resonating at approximately the desired capacitance. It is not necessary that C_2 be exactly four times C_1, but it is necessary that it be tuned for exact resonance as indicated by minimum plate current. It is also necessary that adjustments begin with C_3 at *maximum*. Proper loading can often be obtained with two values of C_3—one very low and the other very high. The high-capacitance setting is correct, and operating at the low-capacitance setting will result in strong harmonic radiation.

Figure 5–64 shows a circuit popular for high-frequency transmitters. If the transmission line is ¼ wave length, or any odd quarter of a wave length, it will effectively suppress the second harmonic. (The antenna must be voltage fed, that is, its length must be an even number of quarter wave lengths from the point where the feeders are attached to the ends of the antenna). To prevent the feeders from radiating, the stray capacitance between the tank and the feeder coil is reduced by coupling through a link circuit. A shield could be placed between the tank circuit and the pick-up coil, but the link is more simple and, in this case, quite effective. The link must be placed at the grounded end of the tank inductance. This circuit has the advantage of being simple to adjust.

Assuming 2000 ohms antenna resistance and a line of 500 ohms characteristic impedance,[10] the second harmonic reduction should be equivalent to a K of 16. This, combined with a tank circuit K of 20, will reduce the second harmonic to 0.1 percent. At the third harmonic, however, the feeders are not nearly as effective in reducing harmonics and the effective K may be as low as 2. This results in a third harmonic of 0.1 percent (just about as strong as the second). This can be reduced somewhat by the use of properly shielded loading coils. These coils can be tuned by a series condenser at the fundamental, but they will assist in keeping the feeder input impedance high at harmonics.

Figure 5–65 shows a circuit which is frequently misused. Depending too much on the push-pull feature, low K values in the tank are frequently ap-

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[10] Characteristic impedance of a 2-wire line is 276 log D/d, where D is the spacing and d is the diameter of either wire.

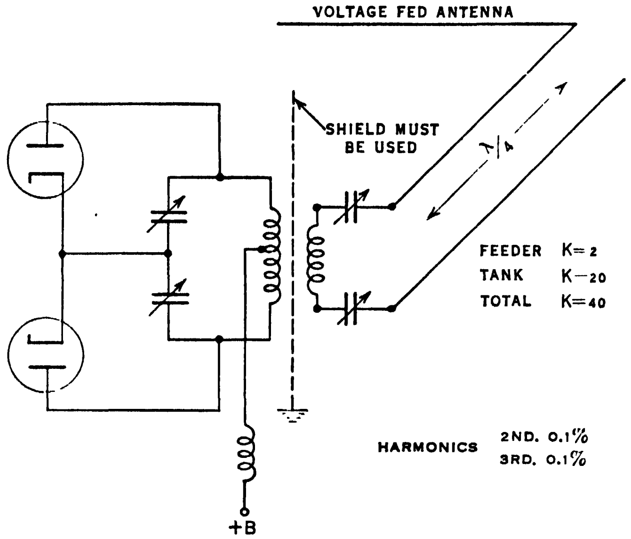

Fig. 5–65. Inductance coupling to transmission line. Voltage-fed antenna circuit.

plied. Unless an effective shield is employed between the tank circuit and pick-up coil, a strong second harmonic can be transferred. In addition, if the feeders are ¼ wave length, they will have but little effect in reducing the third harmonic. To prevent excessive harmonic radiation with this circuit, the tank *K* should be generous—20—and loading coils should be placed in the feeder lines. It is, of course, essential that a Faraday shield be placed between pick-up and tank coil. If link coupling is used, one side of the link should be grounded because the entire tank coil is above ground potential for the second harmonic, that is, there is no grounded section where the link may be applied, as is the case with a single-ended amplifier. The center of the tank inductance is at ground potential for the fundamental and odd harmonics but not at ground potential for the even harmonics. With proper precautions, the second harmonic should not be radiated and the third harmonic should be 0.1 percent or less.

Figure 5–66 is to be recommended over Figure 5–65 *if it is carefully adjusted.* With a *K* of only 6 in each circuit, the third harmonic should be only 0.013 percent. This excellent reduction can be obtained *only if the shielding between tank coil and feeders is complete.* Without effective shielding, both second and third harmonics can be very strong. It is difficult to appreciate the great difference between the capabilities of Figure 5–65 and this circuit which is so similar. The main advantage is the reduction of the third harmonic 9 times (harmonic number squared) due to the use of capacitive coupling and the increased *K* obtained by addition of a second tank circuit (the coupling circuit). Much of this advantage will be lost if the circuits are not properly resonated, or if the shielding is not thorough.

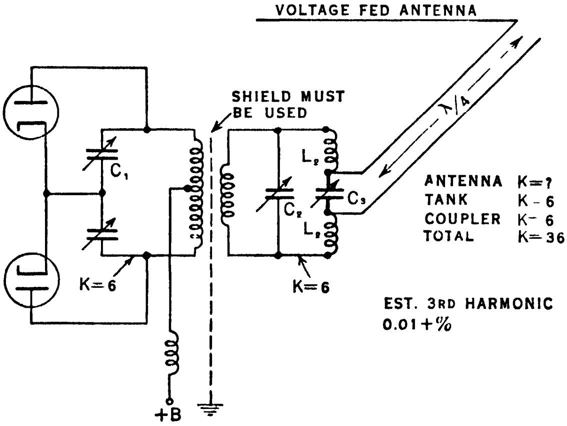

Fig. 5–66. An excellent circuit for suppression of harmonics.

Figure 5–67 is an example of the excellent results that can be obtained by good design. This circuit is used in transmitters manufactured by RCA. The antenna circuit is tuned, thereby securing a *K* of about 6 (it varies with each installation, but can usually be made this high). The intermediate circuit, to which the antenna is capacitively coupled, has additional *K*, 6 being the usual amount. The push-pull tank circuit is also proportioned to have a K of 6. The over-all K is 6 × 6 × 6 or 216. Combined with capacitive coupling, this provides a third harmonic reduction computed as 0.002 percent. The second harmonic is difficult to estimate as it depends upon the degree of balance between the tubes and the effectiveness of the electrostatic shield. It may be safely assumed that with careful construction and balance, the harmonic radiation will meet the strictest requirements. The remarkable performance shows clearly the importance of proper circuit arrangement and shielding.

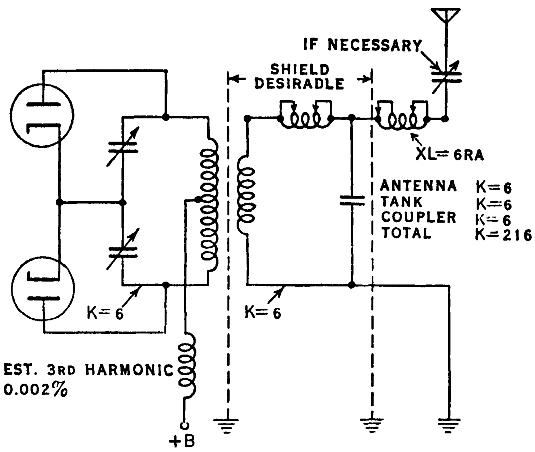

FIG. 5–67. Another excellent circuit for harmonic suppression and proper impedance matching.

5–81. Relation between K and Tank Capacitance—In order to complete the design of output circuits, it is necessary to determine the tank capacitance necessary to produce the desired value of *K*. This depends upon the frequency, the output voltage, and the output current.

The *K* of a tank circuit is found by dividing the tank circuit circulating volt-amperes by the watts delivered to the load:

$$K = \frac{VA}{W} = \frac{E_t I_t}{E_0 I_0} = \frac{E_0 I_t}{E_0 I_0} = \frac{I_t}{I_0}$$

I_t is the *circulating* tank current, I_0 is the alternating current flowing *through* (not circulating in) the tank and also through the power source, which ordinarily means the plate circuit of a tube. In a well-designed tank circuit I_t is larger than I_0. I_0 is in phase with the voltage, but I_t is not. There is but one a-c voltage involved here since the tank is across the tube and necessarily $E_t = E_0$, *provided that the whole tank is actually connected across the* tube. The tank current I_t depends upon the output voltage and the reactance of the tank condenser X_c; so that we can substitute:

$$K = \frac{E_0}{X_c I_0} \quad \text{or} \quad X_c = \frac{E_0}{K I_0}$$

This equation is useful only if it is possible to measure the a-c plate voltage and current, not usually a convenient procedure. The numbered paragraphs below give practical rules for avoiding a-c measurements. If a complete solution has already been made and I_0 and E_0 are known, this equation is a simple means of finding the tank capacitance.

Example: The desired operation calls for a peak output voltage of 1350 and a peak output current of 0.592 amp. Find the tank capacitance necessary to give a tank *K* of 20. The operating frequency is 750 kc. The tube is not neutralized.

Solution: Solving the equation for the tank condenser reactance:

$$X_c = \frac{E_0}{K \times I_0} = \frac{1350}{20(0.592)}$$
$$= 114 \text{ ohm condenser reactance}$$

Note that E_0 and I_0 can be either peak or rms values as long as both are the same. At the operating frequency this reactance requires a capacitance of:

$$C = \frac{1{,}000{,}000}{2\pi f X_c} = \frac{1{,}000{,}000}{6.28 \times 750{,}000 \times 114}$$
$$= 0.00186 \text{ microfarad}$$

The factor of 1,000,000 is introduced to convert farads into microfarads.

Note: For push-pull amplifiers, use the output current and output voltage *per tube*, and the result will be the capacitance of each half of the condenser.

In designing amateur transmitters, or in checking a transmitter already in operation it is desirable to have some rule for deciding tank capacitance without the necessity of a complete solution of output voltage, output current, etc. This can be done by using these relations:

1. In Class C amplifiers the peak output voltage is nearly equal to the plate voltage. Thus for a rough rule we may use:

$$E_0 \text{ peak} = 0.9E_b$$
$$\text{or} \quad E_0 \text{ rms} = 0.636E_b \quad \text{(for Class C amplifiers)}$$

In Class B amplifiers the peak output voltage is somewhat less than half the plate voltage. For a rough rule we may say:

$$E_0 \text{ peak} = 0.4E_b,$$
$$E_0 \text{ rms} = 0.28E_b \quad \text{(for Class B amplifiers)}$$

2. In both Class C or Class B amplifiers there is a fairly definite relation between the output current and the direct plate current. For a rough rule we may use:

$$I_0 = 0.9I_b$$

These rough assumptions may be substituted in the equation for tank condenser reactance, and we have:

$$X_c = E_0/KI_0,$$
$$X_c = \frac{0.57E_b}{KI_b} \quad \text{(for Class C)}$$
$$\text{or} \quad X_c = \frac{0.25E_b}{KI_b} \quad \text{(for Class B)}$$

For rapid calculations, the frequency may be included so that the capacitance can be found in one operation. In this form:

$$C = \frac{279{,}000KI_b}{fE_b} \quad \text{(for Class C)}$$

where C is in micromicrofarads
I_b is in milliamperes
f is in kilocycles
E_b is in volts

These units have been chosen because they are the ones most commonly used.

For Class B, the constant is simply changed:

$$C = \frac{638{,}000KI_b}{fE_b}$$

The use of these equations will be illustrated by a typical example:

Example: The tank circuit C, L, of Figure 5–66 should have a K of 6. What capacitance per section will be necessary? The frequency is 7020 kc, and the total plate current is 200 ma at 1250 volts, in Class C.

Solution: For the capacitance per section it is necessary to use the plate current per tube, or 100 ma. Substituting:

$$C = \frac{279{,}000 \times K \times I_b}{f \times E_b} = \frac{279{,}000 \times 6 \times 100}{7020 \times 1250}$$
$$= 19 \text{ micromicrofarads per section}$$

The resultant of the two condenser sections in series is one half of this.

Note that the K depends upon the plate current. This explains why reduction of the coupling reduces harmonics—actually the K is being increased, and the same result could be accomplished by increasing the tank capacitance the proper amount. For a push-pull stage the proper procedure has been indicated. For a grid-neutralized single-sided stage the plate tank circuit is not tapped, hence the procedure given for single stages is correct. For a plate-neutralized stage, C is ¼ as great if the cathode tap is central as it should be—but keep clearly in mind that this C is the capacitance across the ***entire*** tank coil, whether a single condenser or two in series.

5–9. Neutralization of R-f Amplifiers—The neutralization of r-f amplifiers has already been discussed in the preceding chapter; however, there is given below several practical methods by which the neutralization adjustment can be accomplished.

One point should be noted—neutralization takes care of feedback through the interelectrode capacitance of the tube but should not be expected to combat assorted feedbacks external to the tube. These should be eliminated initially by shielding, filtering, and suitable placement of components. Although some neglect can be compensated for by misneutralizing, the result is an unstable stage as soon as the frequency shifts slightly—perhaps even to sidebands.

5–9a. Adjusting Neutralization by Grid Meter Method—When the stage to be neutralized is provided with a grid current milliammeter, the meter may be used to indicate neutralization by proceeding in the following manner:

1. Remove plate voltage from the stage to be neutralized. This must be done on the power supply side of the r-f chokes and by-pass condensers as they may affect the adjustment. If possible, the best way to accomplish this is to remove the rectifier tubes from their sockets. This can be done, of course, only if the same rectifier does not supply any of the preceding stages.
2. Set the neutralizing condenser at maximum capacitance or with inductive feedback systems, place the coils close together.
3. Apply plate voltage to the preceding stages. Grid current should be indicated in the stage being neutralized.
4. Rotate the plate tuning condenser of the stage being neutralized. When resonance is reached, the grid current will dip noticeably.
5. Reduce the neutralizing capacitance a little at a time, noting the grid current dip each time a change is made. As the correct setting is approached, the grid meter dip will become less pronounced. When perfect neutralization is obtained, the grid current meter will not be affected when the plate tuning condenser passes through the point of resonance. In push-pull stages change both neutralizing condensers at the same time, always keeping their capacitance equal. With inductive neutralization, separate the coils a little farther each trial until the location is found where the grid current will not dip.

5–9b. Adjusting Neutralization with Neon Bulb—When the stage to be neutralized has no grid current meter, a small neon bulb may be used to indicate neutralization. This is not as precise a method as that described above because (1) the neon bulb requires a certain minimum voltage before it will light, and (2) the operator's hand may disturb the circuit so that exact neutralization is lost when the hand is withdrawn. This, of course, cannot be detected and is frequently unsuspected. At any rate, follow steps 1, 2, and 3 of the grid current method (above). Then:

4. Rotate the plate tuning condenser until the neon bulb lights when held close to the tank inductance. If no light is obtained at any setting, touch the glass of the neon bulb to the tank conductor. This makes the bulb somewhat more sensitive but should not be done unless necessary because of the danger of damaging the bulb. When the bulb is lighted, decrease the neutralizing capacitance until the bulb becomes very dim. A slight readjustment of the plate tuning condenser will restore a portion of the brilliancy. Continue reducing the neutraliz-

ing capacitance until the bulb goes out and cannot be made to light at any setting of the tank condenser. In push-pull amplifiers reduce both neutralizing condensers equal amounts each time, always keeping their capacitances equal. With inductive neutralization, separate the coils gradually until the lamp will not glow.

5–9c. Adjusting Neutralization by Tank Current Method—With high-power transmitters, the best method of neutralization is by the use of a sensitive r-f ammeter in the tank circuit of the stage being neutralized. The only disadvantage of this method is the danger of burning out an expensive instrument if extreme care is not exercised. Proceed as follows:

1. Remove the plate voltage from the stage to be neutralized.
2. Replace the normal tank current meter by one having a much lower scale range. Full scale should be about 1/10 of the normal tank current.
3. Set the neutralizing condenser(s) at maximum capacitance.
4. Apply power to the preceding stages.
5. Resonate the tank condenser of the stage being neutralized *very cautiously*. Observe the tank current meter continuously as resonance is approached, and stop if the r-f meter reaches full scale.
6. When the r-f meter reaches full scale (or the highest reading that can be obtained is reached), reduce the neutralizing capacitance until the lowest possible meter reading is obtained.
7. Readjust the tank circuit tuning slightly for maximum tank current reading on the meter. After this point is reached, adjust the neutralizing capacitance again until the minimum meter reading is obtained.
8. Repeat step 7 until a setting is found where no indication of tank current can be obtained on the meter.
9. If a more precise adjustment is desired, the meter may now be replaced with one even more sensitive. Repeat steps 7 and 8.

Failure to obtain perfect neutralization may be due to stray coupling between the coils or leads of the driving circuits and the circuit being neutralized. The antenna coupling coil and load should always be connected when neutralizing the final amplifier stage.

5–9d. Neutralizing with a Flashlight Bulb—A flashlight bulb is a sensitive and inexpensive r-f indicator and is frequently employed in neutralization. The bulb should be connected in series with a single turn of wire. This turn should have approximately the same diameter as the plate circuit tank inductance. The bulb socket forms a convenient base upon which the wire loop can stand.

The single turn is placed close to the tank coil and the bulb will light when r-f current flows in the tank. The sensitivity is adjusted by changing the distance between the tank coil and the loop of wire. Neutralization is carried out in the manner described above until a setting is found at which no r-f current is indicated by the flashlight bulb.

5–10. Parasitic Oscillations—When a transmitter performs in an erratic manner without apparent cause, the trouble is usually some form of parasitic oscillation. Parasitics are defined as oscillations at some frequency other than the fundamental or a harmonic. Many new transmitters are troubled this way. In manufactured transmitters, parasitic tendencies of the original design are usually remedied before production is begun. The exact duplicates manufactured thereafter should be free from parasitics although this is not always the case. Quite frequently minor changes made to expedite production or to simplify assembly may cause new parasitics which must be corrected when the transmitter is installed.

As each transmitter offers different possibilities for parastics no textbook can hope to outline the causes and remedies fully. However, the general principles are known, and several of the more common causes are easily remedied. A careful study of these causes will assist in correcting the faults of any particular installation.

Parasitic oscillations can be produced if any portion of the plate circuit is resonant (or nearly so) with any portion of the grid circuit, thus forming a tuned-plate, tuned-grid oscillator circuit. A further condition is that sufficient feedback must be present. Parasitic oscillation can also be established if any element of the tube shows a negative resistance (dynatron action) characteristic, and there is a resonant circuit in series with this element.

5–10a. Analysis of a Typical Circuit for Parasitic Tendencies—Figure 5–68 shows a conventional, well-designed, amplifier stage including the associated power supply filter circuits. In Figure 5–69, the circuit has been redrawn to show that the grid and plate supply filters form tuned circuits which resonate at very low frequencies—perhaps 1 to 25 cycles per second. At such frequencies, the r-f inductances have no appreciable reactance and are shown simply as conductors. On the other hand, small capacitances are practically an open circuit. The remaining circuit elements form a tuned-plate, tuned-grid circuit. Fortunately, at these low frequencies the internal plate-grid capacitance of the tube is too small to permit sufficient feedback to sustain oscillation. However, grid and plate supply filters are frequently placed so close together that considerable magnetic coupling may be present. If this is the case, oscillation at a very low frequency may result. The remedy for this condition consists of detuning the circuits by using different *CL* products in the grid and plate circuits Notice that the two condensers are in series as far as this oscillation is concerned. It is more economical to use the higher product in the grid circuit because, for the

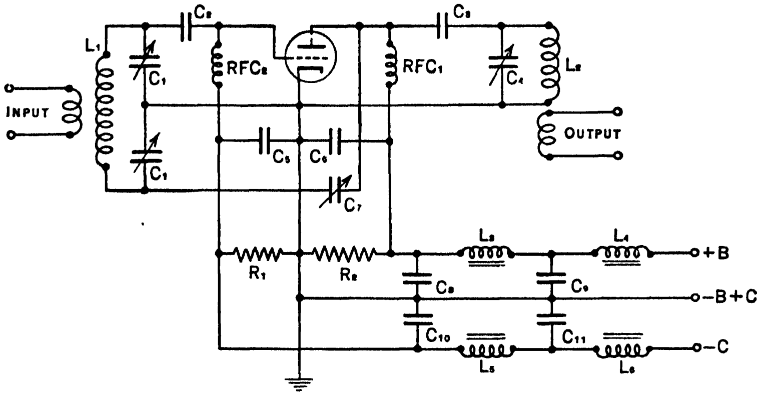

FIG. 5–68. Conventional amplifier circuit of good design to illustrate causes of parasitic oscillations.

L1—Grid tank inductor.
L2—Plate tank inductor.
L3—Plate supply filter smoothing choke.
L4—Plate supply filter swinging choke.
L5—Grid bias filter smoothing choke.
L6—Grid bias filter swinging choke.
RCF1—Plate supply r.f. choke.
RFC2—Grid bias r.f. choke.
R1—Grid bias bleeder resistor.
R2—Plate supply bleeder resistor.
C1—Grid tank condenser.
C2—Grid blocking condenser.
C3—Plate blocking condenser.
C4—Plate tank condenser.
C5—Grid bias by-pass condenser.
C6—Plate supply by-pass condenser.
C7—Neutralizing condenser.
C8—Plate supply filter final condenser.
C9—Plate supply filter mid-section condenser.
C10—Grid bias filter final condenser.
C11—Grid bias filter mid-section condenser.

lower voltage and current, the parts are less expensive. In addition, the filter chokes of the grid bias and plate supplies should be separated sufficiently to prevent any magnetic coupling.

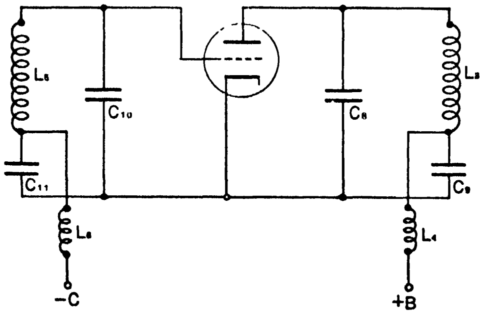

FIG. 5–69. The grid bias and plate supply filters form low-frequency tank circuits. This portion is not neutralized.

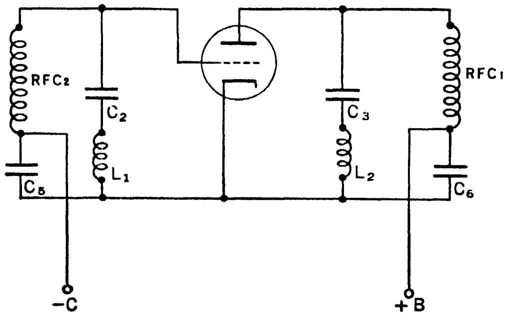

FIG. 5–70. The r-f chokes and by-pass condensers form a pair of tank circuits. This portion is not neutralized.

The grid and plate r-f choke coils often form the inductances of a tuned-plate, tuned-grid oscillator, as can be seen by redrawing Figure 5–68 in the manner shown as Figure 5–70. With usual constants, these circuits resonate at a frequency somewhat lower than the normal operating frequency. In low-frequency transmitters, this usually occurs in the audio-frequency region and the internal plate-grid capacitance is not large enough to cause oscillation. In intermediate- or high-frequency transmitters, the choke coils and by-pass capacitors resonate at a frequency such that the interelectrode grid-plate capacitance may be large enough to produce feedback and oscillations. The remedy for this is to use different inductance values for grid and plate chokes. The plate choke should have the *higher* inductance.

Perhaps the most common parasitic oscillation is that which is due to the length of the plate and grid circuit connecting wires. These wires form single-turn inductances which are tuned by the tube capacitances to frequencies in the ultra-high region. At such frequencies the internal plate-grid capacitance provides sufficient feedback, and strong oscillations are easily produced. The leads drawn in heavy lines on Figure 5–71 form these single-turn inductances. The remedy is to detune the circuits. The preferred method is to insert a small r-f choke coil at the point marked *X*. If a suitable inductance value is used, the plate circuit loop will tune to a lower frequency than the grid circuit, thereby preventing oscillations. Although oscillations can be stopped by adding inductance to the grid circuit, it is easier and better to add it to the plate circuit. This is due to the fact that oscillations will persist even when the grid circuit is far off tune on the *low-frequency* side of resonance, whereas oscillations will stop immediately when the grid circuit is tuned to the *high-frequency* side of resonance. The grid leads should, therefore, be as short and direct as possible, and the plate leads should include added inductance (if necessary) to resonate at a lower frequency.

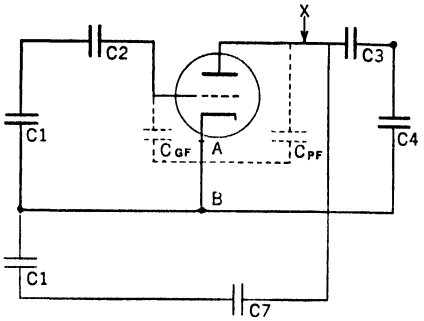

FIG. 5–71. Leads shown in heavy lines form single-turn inductors and aid in the generation of parasitic oscillations.

When two tubes are operated in parallel, a particularly strong oscillation can be set up with the tubes acting as an ultra high-frequency push-pull oscillator. The connecting wires between the two plates and the two grids act as inductances tuned by the tube capacitances. If the tubes are symmetrically arranged (as they usually are), these connections will naturally be equal in length and therefore resonant to approximately the same frequency. Like the previous type of ultra high-frequency parasitic, this can be prevented by inserting small choke coils in series with each plate lead to tune the plate circuit to a lower frequency.

Small plate chokes to suppress parasitic oscillations are frequently paralleled with a noninductive resistor of about 100 ohms. The purpose of this resistor is to increase the losses of the circuit at ultra-high frequencies, and thus make oscillation more difficult. Any sign of heating of these resistors is a certain indication of parasitic oscillations since practically all the fundamental current goes through the choke coil which has very low reactance at fundamental frequencies. Parasitic currents are offered a higher impedance by the small choke and tend to flow through the resistor.

Notice especially that neutralization does not prevent parasitic oscillations. Proper neutralizing voltages are dependent upon resonance to build up a voltage of opposite phase. This resonance is obtained only at the fundamental frequency.

The lead between the cathode inside the tube and the returns from the grid and plate circuits is actually a portion of both circuits. This is seen on Figure 5–71 marked *A* and *B*. This lead presents an inductive reactance which varies with the frequency and directly couples the grid and plate circuits. Ordinarily this coupling provides a voltage of improper phase to cause oscillations. At ultra-high frequencies, the remaining portions of the circuit will introduce phase shifts which may permit oscillations. The lead should be made as short as possible. A further advantage of shortening this lead is to make the neutralization adjustment less dependent upon frequency. This is a valuable feature when frequencies are changed often.

Negative-resistance parasitics appear from a variety of causes, the most usual of which are listed here:

(*A*) The plate may show a negative resistance characteristic when the screen voltage of a tetrode or pentode is higher than the instantaneous plate voltage. This is the usual dynatron action. A similar effect can occur in triodes when the grid voltage is higher than the plate voltage. This condition is obtained during negative modulation peaks on a Class C plate-modulated amplifier. The resulting negative resistance can produce a momentary oscillation in any tuned circuit in series with the plate. This kind of parasitic is hard to locate because it can exist only during negative modulation peaks. As the plate voltage is rather low at that time, the power in the parasitic is limited and little damage will be done. The main effect will be distortion when the necessary high percentage of modulation is reached The suggested remedy is parasitic chokes in series with the plate. They should be shunted with resistors. This makes the resistance of the circuit greater than the negative resistance generated by the tube, and oscillations cannot be produced.

(*B*) When the grids of a tube are driven extremely positive, secondary emission may take place from the grids. This reduces the grid current and may proceed to such an extent that an increase in grid voltage produces a reduction in grid current—i.e., a negative resistance. If this happens, any resonant circuit in series with the grids can oscillate. The remedy for this type of oscillations is to load the grid circuit with resistance. In Class B amplifiers this is ordinarily done to improve the regulation of the driver stage. However, present-day tubes are carefully designed to minimize secondary emission so that this type of trouble is not common except where tubes are improperly operated.

(*C*) An unexpected source of negative resistance is discovered when a curve is plotted for r-f output versus grid excitation in Class B r-f amplifiers. A decided "kink" sometimes appears in the region where the grid voltage becomes positive. This can be seen on Figure 5–72 which shows a typical saturation curve. From point *A* to point *B* the output fails to increase properly with an increase in excitation. Ordinarily Class B amplifiers are operated at a constant plate voltage and no curves are ever taken of plate voltage vs. plate current. Mr. A. D. Ring, Consultant, found that with the grid excitation at the point of the "kink" in the saturation curve, a negative resistance characteristic is found in the plate current-plate voltage curve. This can cause oscillations in any resonant circuit which is in series with the plate. A frequent case is oscillation at very low frequency in the plate supply filter. Although these oscillations can be prevented by a bleeder resistance across the plate supply, the only satisfactory remedy is to make sure that the unmodulated excitation is *not* at the level of the kink. With this precaution, the negative resistance of the plate circuit will appear only momentarily as the excitation passes through the critical point during modulation.

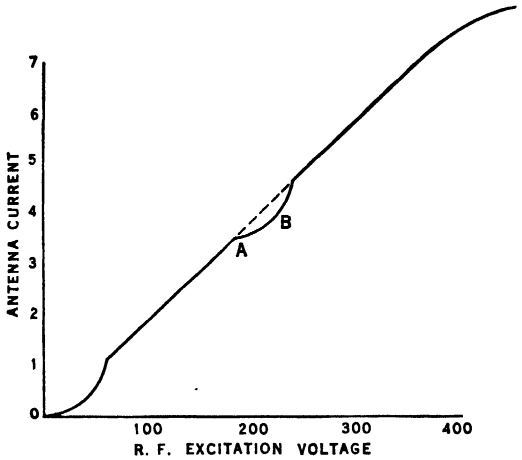

Fig. 5–72. Typical saturation curve.

(*D*) A very troublesome source of negative resistance is the presence of gas in a tube that has been overloaded (gas released from the elements), improperly evacuated, or aged. Although ingenious operators have devised various remedies, the only certain solution is to remove the tube from service and replace it with a good one. In this connection, operating the plate circuit slightly off resonance is very beneficial in keeping large tubes free of gas. A suggested amount is to increase the tank capacitance beyond resonance until the plate current rises 5 percent.

5–10. Butterfly Circuits—Transmission lines are frequently employed to perform the functions of resonant circuits at very high frequencies, since in the region near resonance the curve of line impedance as a function of frequency has the same shape as the resonance curve of a circuit with lumped constants. High values of *Q* are obtainable at very high frequencies, particularly when concentric lines are employed. However, they are not the ideal substitute for a lumped tuned circuit, since certain problems in tuning are involved, including that of changing the length of a line without introducing losses and erratic variations.

These problems prompted the General Radio Company to investigate the possibilities of circuits with lumped parameters and led to the development of circuits having a high degree of merit and a range of frequencies between 100 and 3000 mc. General Radio identifies these tuning devices as "butterfly circuits" because of the shape of the rotors.

The first step in the development of a high-*Q* lumped-tuned circuit was a wavemeter having a conventional tuning condenser and a single-turn inductor consisting of a metal band fastened to a ceramic ring and mounted coaxially. The stator of the condenser was connected to one end of the metal band, and a metal brush on the condenser rotor shaft made contact with the band. The band covered an arc of 270°, corresponding to the rotation of the condenser, and the length of the band between rotor and stator increased with the increase of capacitance. This arrangement comprised a tuned circuit consisting of a capacitance variable from 12 to 85 $\mu\mu$f and an inductance variable from 14 to 99 cm. It covered a frequency range from 55 to 400 mc. Resonance was indicated by an incandescent lamp or a small glow-tube carried on the rotor arm.

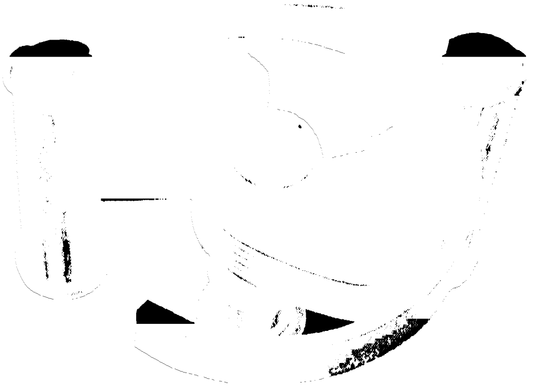

Fig. 5–73. Contact type tuning unit covering range from 60 to 660 megacycles. (Courtesy General Radio.)

The range could be extended to lower frequencies by adding capacitance, but the top frequency was limited by the minimum capacitance of the tuning condenser and by the relatively large inductance of the connection to the metal band.

Further experimentation to extend the top frequency led to a design shown in Figure 5–73 in which the capacitance varied between 7.4 and 118 $\mu\mu$f and the inductance between 7.8 and 59 cm, giving a frequency range of 60 to 660 mc. In this

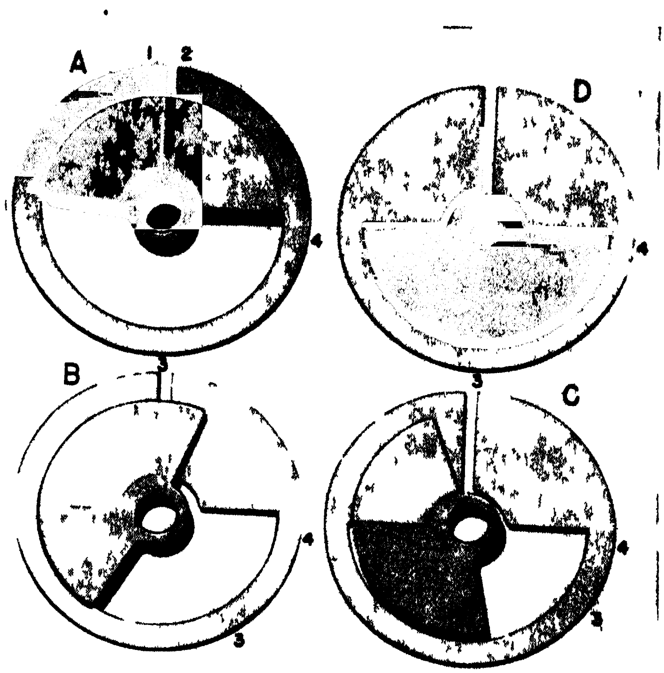

Fig. 5–74. Stator and rotor plates of semi-butterfly tuning circuits. Capacitance and inductance between points 1 and 2 on the stator are at maximum in A and minimum in D. (Courtesy General Radio.)

device the law of inductance variation was determined by the design, but the frequency distribution was determined by shaping the condenser plates so that there was produced a straight-line logarithmic frequency scale which is always desirable for an instrument covering a wide frequency range. The unused part of the inductance band projecting beyond the point of contact, was closely coupled to the tuned circuit and resonated at a high frequency. The end of the band was usually connected to the rotor to keep the resonant frequency outside the range of the tuned circuit.

While the top tuning range was extended in this design, it had the disadvantage of sliding contacts which require a certain amount of care to insure low losses and trouble-free operation. These difficulties could be avoided by replacing the contact spring by a capacitance member, but suppression of resonance effects, obtained by shorting the end of the band to the rotor, is then no longer effective. Consequently, the top frequency of the circuit had to be covered, and since the bottom frequency is raised owing to the series capacitance of the contact, the tuning range is reduced considerably.

5–10a. Tuning Units Without Contacts—The next stage in the experimentation led to a design identified as the semibutterfly, as distinguished from the butterfly circuit.

In all the circuits discussed previously the highest resonance impedance was developed between a point on the rotor and a point on the stator. In the semibutterfly circuit the highest impedance appears between two points on the stator. The stator consists of a semicircular band connecting two pairs of sectorially shaped plates. To change from the lowest-frequency position, shown as *A* in Figure 5–74, to the highest-frequency position, marked *D*, the rotor is turned through 180°. In position *A* the capacitance between points 1 and 2 on the two stator plates is at maximum. In position *B* the capacitance is almost at minimum and changes only slightly until position *D* is reached. The inductance between points 1 and 2 is likewise at maximum in position *A* and changes to minimum over position *B* and *C* to position *D*. The change in inductance of the semicircular band is brought out as the rotor gradually fills up the opening of the inductance loop. In the final position *D* lines of magnetic flux are restricted to the small clearance between rotor and stator. In this design, wide tuning range with simultaneous change of lumped capacitance and inductance is obtained by rotation of a member that does not require any electrical connections. The rotor shaft can be made of insulating material, and the flow of radio-frequency currents through the bearings of this shaft is easily avoided.

Several other designs of semibutterfly circuits were developed, for example, one that is employed in an oscillator having a frequency range from 100 to 500 mc. In this circuit the stator plates use 120°

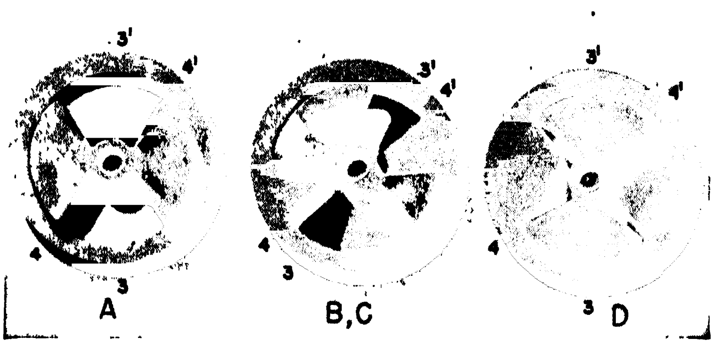

FIG. 5–75. Stator and rotor plates of the butterfly tuning circuit. Capacitance and inductance between points 1 and 2 on the stator are at maximum in A and minimum in D. (Courtesy General Radio.)

sections and 240° sections for the rotor, the rotor turning through 120°.

5–10b. The Butterfly Circuit—A modification of the arrangements previously described was made by Dr. A. P. B. Peterson and accomplished a certain amount of electrical symmetry by opening up the two circuits and connecting them in parallel. The result is the butterfly circuit shown in Figure 5–75.

In Figure 5–75, *A, B, C,* and *D* correspond to the positions shown in Figure 5–74. Points 3 and 3′ are the electrical midpoints between terminals 1 and 2, and points 4 and 4′ are the locations for magnetic coupling.

While the losses in butterfly circuits cannot be made as low as in concentric lines, values of Q can be obtained that are sufficient for many applications. The resonant impedance of butterfly circuits is well within the range of plate resistance of vacuum tubes and changes very little from the low- to the high-frequency end. This makes it possible to produce oscillations over the tuning range.

5–10c. Electrical Dissymmetry—In the tuning devices described above there are two impedance terminals designated as 1 and 2 in Figure 5–74. No point on any of the circuits maintains electrically its position relative to these terminals over the tuning range in the sense, for instance, of a tap on a coil, with respect to the ends of the winding. In Figure 5–74 point 3, midway electrically between the terminals, is symmetrically located only in the two extreme positions *A* and *D* and shifts toward terminal 2 for intermediate settings. The potential of the rotor is midway between points 1 and 2 in position *A* and *D* but shifts toward terminal 1 for intermediate settings. This fact is an important consideration in all applications.

Any point of the circuit can be connected to ground, but it is convenient at times not to make any definite connections. This might be desirable in an oscillator circuit, for instance, where the plate and grid of a tube are connected to the two terminals and where the cathode is grounded.

5–10d. Coupling to Load—The optimum method of coupling a load to the circuit depends upon the ground arrangement. If one terminal is grounded, electrostatic coupling is most convenient. When the circuit is left floating, electromagnetic coupling is more desirable. The only point where effective magnetic coupling over the entire tuning range can be obtained is shown as point 4 in Figure 5–74.

5–11. The Klystron—Conventional tubes do not lend themselves to the efficient generation of r-f energy in the microwave spectrum, since a certain period of time is required for the electrons to travel from the cathode to the plane of the grid. The elapsed time is a fraction of a microsecond and is called the *transit time*. At a frequency of 1000 mc, the time for one cycle is 10^{-3} microseconds and, in all but special tubes, electrons cannot reach the plane of the grid in this brief period. Consequently, the grid voltage passes through a large portion of its cycle during the time the electron is in flight. In this case only a few electrons pass beyond the plane of the grid to the plate since, when the grid voltage is sufficiently positive to allow the passage of electrons, the grid voltage has passed through half or more of its cycle and now, becoming negative, proceeds to repel the electrons which have not reached the grid. The transit time must in general be less than ⅒ the time for one signal cycle for satisfactory operation. Excessive transit time reacts as increased input loading which tends to limit the use of conventional tubes at ultra-high frequencies.

Velocity modulation of the electron stream, similar to that accomplished in a cathode-ray tube, provides a method of overcoming the handicap of the transit time. Tubes employing velocity modulation were devised by R. H. Varian and S. F. Varian at Stanford University and were subsequently developed by the Sperry Gyroscope Company, and registered under the trade mark of "Klystron." The term "Klystron" is applicable to an ultra-high frequency amplifier or generator which combines the velocity modulation principles with one or more cavity resonators to produce and/or utilize a velocity-modulated beam of electrons.

The basic principle is that of periodically changing the velocity of electrons passing a certain point in a tube and allowing these electrons of different velocities to form bunches by drifting through the required distance. These bunches will form due to the faster electrons catching up with the slower ones at a given point in the tube. They occur once each cycle of the frequency to be generated if allowed to travel through the tube for some convenient distance, since time is required to form the bunches or groups. The bunches of electrons are made to deliver their energy to a resonant circuit of special design, as will be described later.

These groups of electrons, coming as they do at periodic intervals, act in a manner similar to a periodic impulse causing a pendulum to oscillate at a regular frequency and amplitude or, in other words, producing waves analogous to continuous radio waves.

5-11a. Cavity Resonator—The most important component of the Klystron is the resonant circuit or cavity. It is well known that at ultra-high frequencies a point is reached where a single loop of inductance and pair of condenser plates will no longer serve to produce the desired frequency, since the losses become tremendous. However, since inductances in parallel have less inductance than one alone, it is possible to add a number of loops in parallel to decrease the inductance.

Figure 5–76 shows the evolution of a toroid cavity resonator. It will be noticed that the inductance loops are placed between the same pair of condenser plates. The result is a doughnut-shaped ring slotted within the hole at the shortest diameter, with two plates placed parallel to the axis of the doughnut, one at each edge of the slot, so that it appears to be only a solid doughnut-shaped object with a short plug in the center. The doughnut becomes smaller as the frequency is increased. Cavity resonators, like transmission lines, have more than one resonant frequency, as, for example, a long transmission line has an infinite number of resonant frequencies, which occur when the length of the line is an integral number of quarter or half wave lengths. In this case there will be nodes of current and voltage equally spaced along the line. A single number in such a case is sufficient to specify the order of the harmonic frequencies as related to the fundamental. In a cavity resonator it is possible to have current or voltage nodes in three dimensions and, consequently, three numbers are required to specify the order of a certain harmonic. The higher resonant frequencies are not integral multiples of the lower ones. It can be seen that this is quite different from the case of a simple coil and condenser circuit, which has but one resonant frequency, provided the dimensions are negligible compared with the wave length.

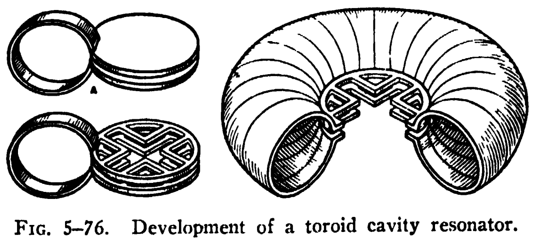

Fig. 5–76. Development of a toroid cavity resonator.

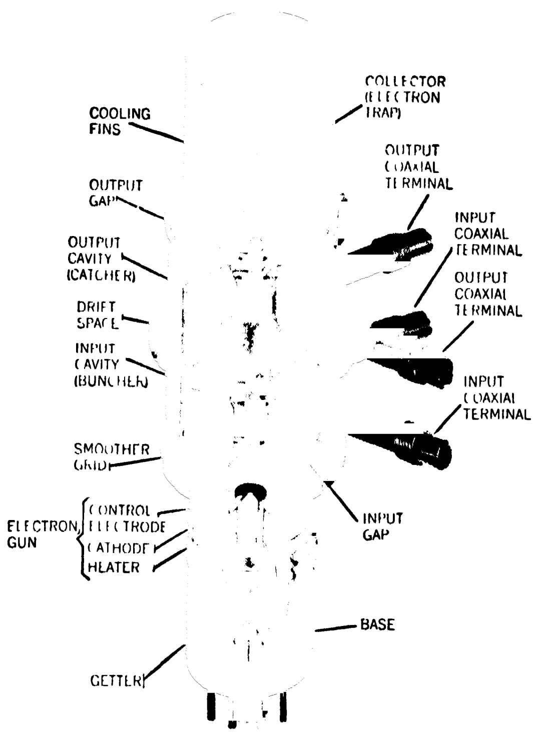

Fig. 5–77. Cut-away view of a Klystron tube.

Figure 5–77 shows a cutaway photograph of the 410R/2K30 Klystron and Figure 5–78 a generalized diagram. The electron gun, which comprises the cathode assembly, furnishes a beam of electrons with a uniform average velocity beyond the anode plane marked "smoother grid." A radio-frequency field between the grids of the resonator, usually called the "buncher," will modify the velocity of the electrons passing these grids. The electrons which have been speeded up by the buncher will overtake, in the drift space beyond the buncher, the electrons which left the buncher earlier but were slowed down during the previous half cycle. As a result, the beam current between the grids of the second or "catcher" resonator will be pulsating or bunched, and if the second resonator is tuned to the bunching frequency the beam will deliver power to the "catcher." Coupling to the resonators is obtained with small wire loops which lead to the coaxial terminals, sometimes referred to as "antenna-seals."

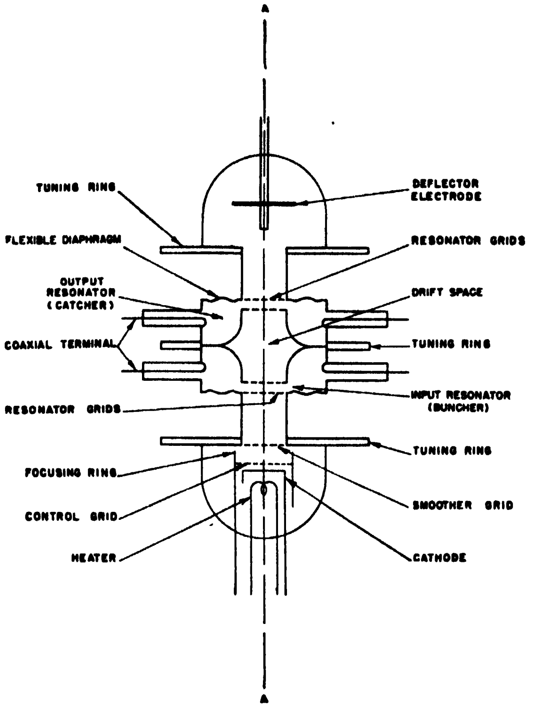

FIG. 5–78. Schematic view of a Klystron. (By permission of Sperry Gyroscope Co., Inc., from Klystron Technical Manual, A. E. Harrison.)

5–11b. Overbunching—The power output of a Klystron amplifier is influenced considerably by the tuning of the input resonator, as shown by Figure 5–79, which shows the output of the output resonator when the tuning of the input resonator is changed. As the input resonator tuning is varied, the buncher voltage will follow the usual symmetrical resonant curve. When the input resonator is badly detuned on one side, the buncher voltage will be less than that required to give maximum output, resulting in decreased output from the maximum value of the output resonator.

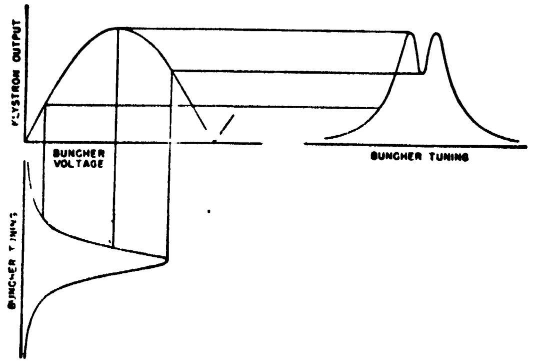

FIG. 5–79. Characteristic curves for a Klystron amplifier.

When the tuning is such that the buncher voltage is correct for maximum output, a peak will be observed in the catcher output. When the input resonator is tuned to resonance, the buncher voltage will be increased and causes a reduction in the output from the Klystron amplifier. Consequently, when the output of the output resonator is plotted as a function of the tuning of the input resonator, the characteristic curve will have a double peak which is typical for overbunched velocity-modulation tubes.

5–11c. Frequency Range of Cavities—Cavity resonators are designed to be operated over a range of several percent of their fundamental frequencies. Tuning is accomplished by a mechanical means of "stretching" the tube to change the distance between the buncher grids and the catcher grids. Figure 5–80 shows a cutaway of a type 410–R Klystron with model 11–C tuner. The frequency of the tube may be altered over a rather wide range by means of the three tuning struts for each cavity. These three struts operate against the center ring midway between the two resonators and stretch the anode end and the cathode end away from the center, thus altering the distance between the buncher and catcher grids. Tension springs are used to keep the end plates bearing against the struts. Close examination of Figure 5–80 will disclose the vernier tuning mechanism and graduated scale. A micrometer type barrel operates a screw and wedge to expand or contract the length of one of the three tuning struts. Other tuning methods are applicable; for example, if the cavity is outside of the tube, tuning may be accomplished by screwing plugs into the

FIG. 5–80. Type 410-R Klystron with model 11-C tuner.

cavity, effectively changing its volume. The frequency of a reflex oscillator may also be changed by variation of either the reflector voltage or the acceleration voltage.

5–11d. Klystron Oscillator—It has been previously explained how oscillations are produced by an amplifier when sufficient energy is fed back from the output to the input with the correct phase relation. Oscillations are generated by a Klystron amplifier by connecting a feedback line in the form of a short coaxial cable between one of the coaxial output terminals and the input to the input resonator as shown in the photograph of Figure 5–81.

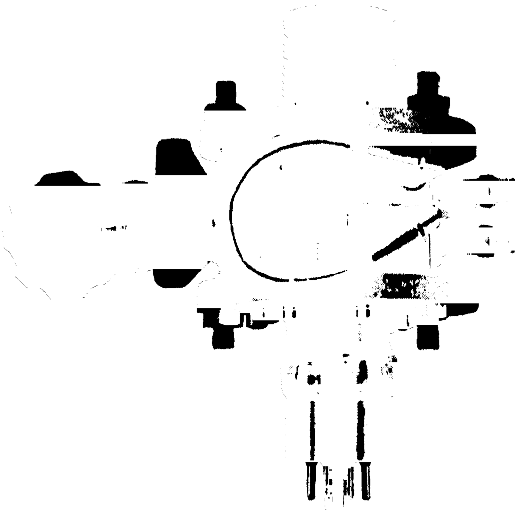

FIG. 5–81. Type 410-R Klystron with model 11-C tuner and coaxial feedback coupling loop

The phase of the feedback depends upon two factors: (1) the relative tuning of the input and output resonators and (2) the transit time between the buncher and catcher grids and, consequently, only a certain beam voltage will satisfy the phase conditions for generating oscillations. To accomplish this the beam voltage must be adjusted to the correct value and the two resonators tuned to the same frequency simultaneously.

5–11e. The Klystron in Frequency Modulation—Since the transit time affects the phase relation in the feedback circuit, there will be a variation of frequency if the acceleration voltage of the Klystron oscillator is changed. This means that a very stable power supply having a minimum of a-c ripple must be employed if the output of the oscillator is to be free of amplitude and frequency modulation. It is obvious that this characteristic of the Klystron oscillator lends itself to frequency modulation merely by varying the acceleration voltage.

5–11f. Klystron Cascade Amplifiers—There is one type of Klystron amplifier which may be considered as a two-stage amplifier within a single tube. In this type of Klystron amplifier the electron gun directs a beam of electrons along the axis of the tube past three cavity resonators. The electronic action is as follows. A small r-f voltage at the grid of the input resonator slightly modifies the velocity of the electrons. A small amount of bunching occurs in the region between the first and second resonator grids. This bunching may not be adequate to give maximum output from the second cavity resonator, but does introduce an r-f voltage at the grids of the second cavity, and this voltage is larger than the voltage at the buncher, which was required to produce the velocity modulation. As a result, the electrons are remodulated by the action of the second resonator or cascade buncher. This additional velocity modulation is sufficient to cause adequate bunching when the electrons reach the position of the third resonator of the cascade amplifier.

5–11g. The Klystron in Frequency Multipliers—A Klystron oscillator produces an r-f current rich in harmonics and consequently lends itself to frequency multiplication. In order to accomplish this, it is necessary that the relative phase of the two resonant cavities be such that bunches of electrons hit the catcher at a time, which will cause the

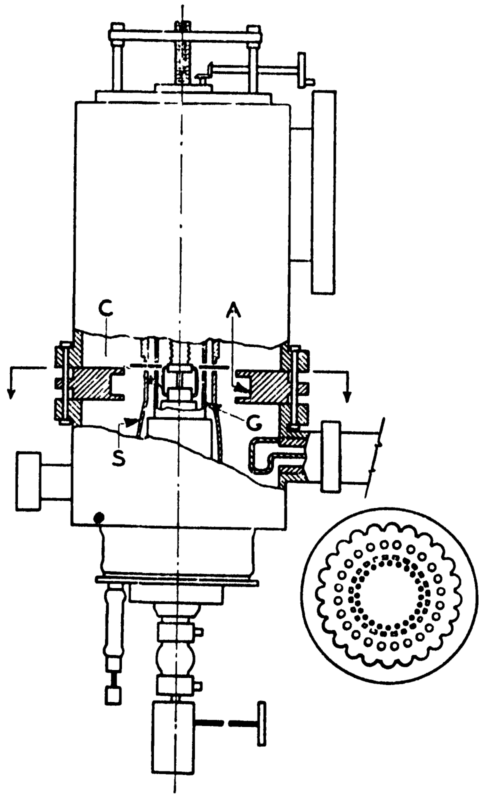

FIG. 5–82. Cut-away view of resnatron and cross section (at arrows). A is the anode, C cathode, G grid, S the accelerator or screen. The close positioning of grid and cathode will be noted. (Courtesy Westinghouse.)

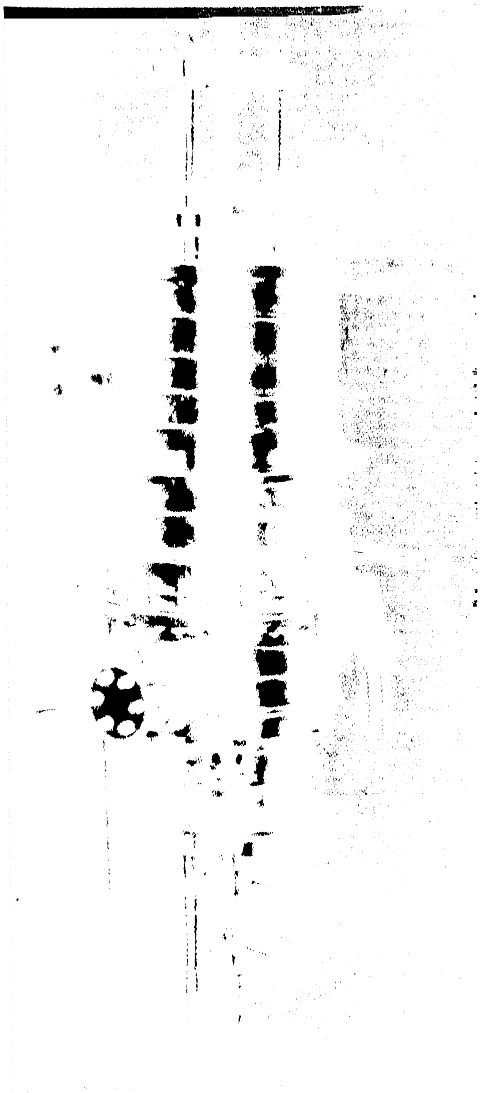

FIG. 5–83. The resnatron. (Courtesy Westinghouse.)

oscillations to build up, and the catcher cavity must necessarily be designed for the harmonic frequency required.

5–11h. Efficiency and Power Output—The power gain from a single-stage Klystron amplifier may be in the neighborhood of 5 to 20. The gain of a three-stage cascade amplifier may be 1000 or more. The ideal efficiency of a Klystron amplifier is 58 percent, but in actual practice efficiencies are considerably less. Radio-frequency power output ranges from less than one watt to several hundred watts.

5–12. The Resnatron—The resnatron, a tube capable of operating continuously with outputs of 50 kw or more in the ultra-high frequency region, was developed in 1938 by Dr. David H. Sloan and Dr. L. C. Marshall at the University of California while seeking a high-power source of high frequency for electron acceleration. During World War II Dr. Sloan and Dr. W. B. Fritter and their co-workers at the Westinghouse Research Laboratories developed models which were used successfully to jam the operation of enemy radar systems.

The design of the resnatron takes into consideration the transit time effect and heat dissipation, both of which are of importance and cannot be avoided at very high frequencies if appreciable power is to be attained.

The resnatron is a tetrode consisting of a cylindrical cathode bearing 24 emitting filaments, a control grid, an accelerating grid, and an anode. The cathode assembly can be seen in Figure 5–82. In addition, the resnatron has two resonant cavities—one between the cathode and control grid, and the other between the accelerating grid and the anode, which operate in a manner similar to the familiar *LC* tank circuit.

The fourth element, or accelerating grid, is employed to insure efficient operation. The ideal method of operation calls for the accelerator to be operated at the same potential as the anode; however it is much simpler to control the transit time by variation of the accelerator grid potential, thereby making the spacing between the electrodes much more critical.

As mentioned in Section 5–11, at very high frequencies, the transit time—the time taken by electrons to travel from the cathode to the anode—becomes so great that the electrons are not moving in the right direction with respect to the (r.f.) field. Employing the analogy of the pendulum, this would be tantamount to continuing the pulse in one direction after the motion of the pendulum had already started in the other. This difficulty can be overcome by decreasing the dimensions of a tube, but no matter how careful the design, some electrons will collide with the tube element and the kinetic energy of these electrons is converted into heat upon striking an electrode and may be of sufficient intensity to melt it.

If appreciable power is to be obtained at high frequencies, the design of the tube must be such that the transit time does not interfere with its operation. In order to obtain high efficiency, it is necessary to have the phase relation such that the electrons start from the grid at such a time that they reach the anode before the (r.f.) field reverses itself.

5–12a. Cathode Characteristics—To insure good power output—50 kw or more—as well as good modulation characteristics, a tremendous demand is imposed on the cathodes of the resnatron. The current density for a unit area is a function of the cathode material and its temperature; hence the most practical way of increasing the power output is to increase the current per unit area from the cathode by increasing its temperature and consequently shortening its life.

Therefore to obtain sufficient current the cathodes of the resnatron are run at such high temperatures that normal life expectancy is 100 hours and, consequently, the cathodes are designed for easy replacement.

5-12b. Cooling—The design of the resnatron grid overcomes many difficulties encountered in trying to provide a high amplification factor and at the same time prevent disintegration of the tube elements by electrons colliding with these elements.

Because of the position of the control grids in the tube and its small size, water cooling is difficult. If the usual practice were followed in construction and the control grid made larger so as to provide for cooling, the resultant increase in grid-to-cathode spacing necessary would result in decreased amplification factor. The design of the resnatron control grid simultaneously overcomes these difficulties in an ingenious manner.

5-12c. Characteristics—Figure 5-82 shows a cut-away view and cross section of the electronic portion of the resnatron. The design features and their effect on the operation of the resnatron are best described in the words of Dr. F. W. Boggs, formerly of the Westinghouse Research Laboratories.[11]

"Because the tube is entirely water cooled, copper tubing figures as one of the most important requirements in its construction. The accelerator is a grid made of copper tubes through which cooling water is circulated. The anode is a coil of copper tube in some of the designs. In others, dependent upon the frequency application, different arrangements are used. In general, however, the anode is cooled by a copious flow of water. The different portions of the tube are brazed together in a hydrogen furnace or, in some instances, soft-soldered or torch-brazed. The few joints necessary for assembly of the tube are bolted with rubber or tin gaskets to assure a vacuum-tight joint.

"The circuit elements of the tube are included in the vacuum envelope of the tube for two reasons: (1) to permit short leads to the circuit elements, and (2) to prevent dielectric heating losses at a glass-to-metal seal facing the tank circuit.

"The first is obvious but the second is the important reason for the inclusion. If the circuit elements of the tube are external, inevitably there must be some tube envelope exposed to the high fields of the tank circuit. This follows from the fact that the high-voltage point of the tank circuit must be electrically joined to the anode. At resnatron operating frequencies this would cause considerable power loss in the glass, creating a violent temperature rise which would demolish the glass. For example, if the power output is 50 kw and the Q is 100, there will be 5000 kw in the tank circuit. The voltages are correspondingly great so that the dielectric-heating effect would be severe. By placing the circuit elements in the interior of the tube, it is possible to exclude the r.f from the insulating materials, thus removing a very serious obstacle to practical tube construction.

"The circuit elements in the resnatron are sections of coaxial line. Two methods of tuning have been used. In the first, the lines are shortened at one end and terminate in a variable condenser at the other end. In the second, the line is shorted at both ends, the position of one short being variable. This end-plug is water-cooled, and the contacts placed at the ends of Sylphons or metal bellows which expand under cooling-water pressure. In this manner, full electrical contact is assured at all times.

"The resnatron is used principally as an oscillator, where feedback is obtained by means of a probe extending from the cathode into the anode cavity. For the resultant phase shift (90°) a suitable transit time is chosen."

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[11] *The Resnatron—A Generator of Microwaves*, Boggs, F. W., *Westinghouse Engineer*, March 1947.

CHAPTER 6

AMPLITUDE MODULATION

Perhaps the best method of approaching the subject of amplitude modulation in radio telephony is first to review briefly the principles governing the operation of the conventional wire telephone.

6–1. The Wire Telephone—The simplest telephone arrangement consists of a carbon microphone, a telephone receiver, and a battery connected as shown in Figure 6–1. A moving sound wave, which is composed of alternate regions of air in a state of compression and rarefaction, causes the diaphragm to vibrate at the frequency and relative amplitude of the sound wave. These vibrations are exerted on a mass of carbon granules enclosed in a small containing cup. The resistance of this mass of carbon granules varies as a function of the applied pressure and, as a result, the magnitude of the battery current flowing in the microphone circuit is varied at a frequency and amplitude corresponding to the frequency and amplitude of the sound wave, as suggested by Figure 6–2. This varying current, in passing through the telephone receiver, is converted back into a sound wave similar to that originally impressed upon the diaphragm of the microphone. The process by which the variations of microphone resistance are superimposed upon the normal value of current is called *modulation*, and the microphone circuit current is said to be *modulated*. The normal value of battery current may be called the *carrier current* because it is the agency which makes possible the transmission of the sound wave in the form of current variations. The variations themselves are called the *modulation* or *modulating current*. The modulated carrier can be considered as being composed of two components —the normal, or carrier, current and the varying, or audio, component produced during the modulation process. Since the amplitude of the carrier current changes during modulation, this process is known as *amplitude modulation*.

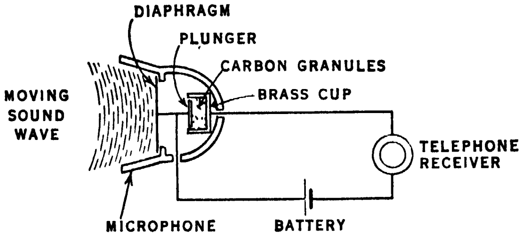

FIG. 6–1. A simple telephone circuit.

From the standpoint of making the most efficient use of a given carrier current, a high percentage of modulation is desirable. In Figure 6–2a, the peak amplitude of the modulating current is equal to one-half the value of the carrier current. In this case, the percentage of modulation is said to be 50 percent. In Figure 6–2b, the peak amplitude of the modulating current is equal to the value of the carrier current. This constitutes 100-percent modulation and represents the maximum and most efficient utilization of the carrier current. Should 100-percent modulation be exceeded, the carrier current actually will be cut off by the negative peaks of the modulating current as shown in Figure 6–2c. The carrier current is then said to be overmodulated and severe distortion will result.

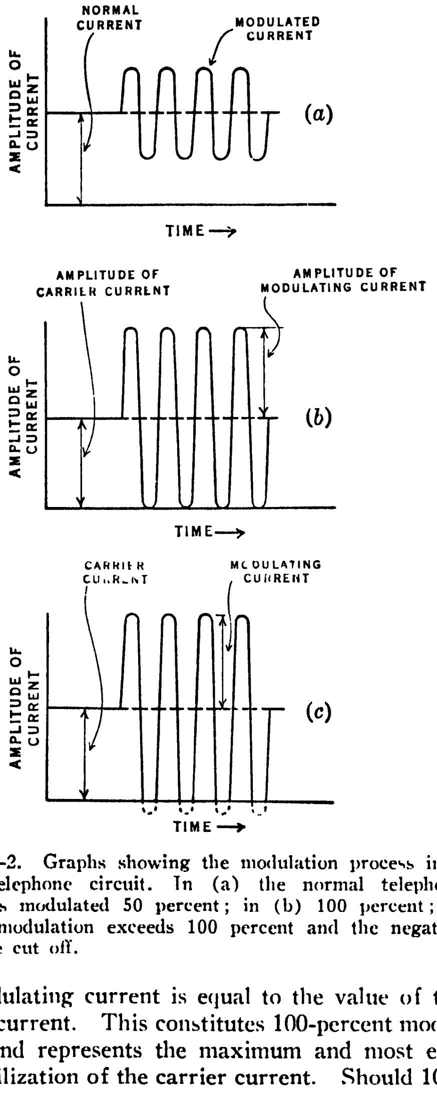

FIG. 6–2. Graphs showing the modulation process in a simple telephone circuit. In (a) the normal telephone current is modulated 50 percent; in (b) 100 percent; in (c) the modulation exceeds 100 percent and the negative peaks are cut off.

6–2. Elementary Methods of Modulation—In amplitude-modulated radiotelephone systems, the battery of the wire telephone is replaced by a radio-frequency generator whereas the telephone receiver is replaced by a radio receiver. The radio-frequency (carrier) current supplied by the generator is radiated by the antenna in the form of electromagnetic waves. A small portion of these waves are converted back into a high-frequency current when they pass the receiving antenna. This current, though small in magnitude as compared to that at the transmitter, conforms exactly in frequency and relative amplitude with the current in the transmitting antenna. Therefore, any change that we may make in the current at the transmitting antenna will be reproduced at the receiver. In other words, we may consider the antenna current at the transmitter to be a carrier current, since any variation in its value will be accompanied by a similar variation at the radio receiver.

A simple method of varying (or modulating) the antenna current is to connect a carbon microphone directly in the antenna circuit as shown in Figure 6–3. Since the antenna current must pass through the microphone, its value will be affected to some extent by the resistance of the microphone. A sound wave actuating the microphone diaphragm causes changes in the microphone resistance and thus produces modulation of the antenna current.

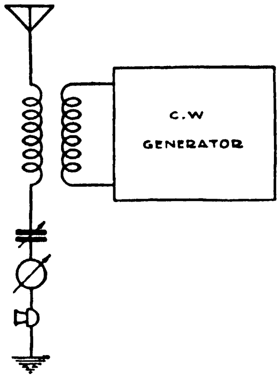

Fig. 6–3. A simple method of modulating a CW carrier.

Another simple method of producing amplitude modulation is shown in Figure 6–4. In this case, the microphone is coupled to the antenna circuit instead of being placed directly in series with it. In Figure 6–4a, the coupling is conductive, while in Figure 6–4b, the coupling is inductive. These methods of modulation are known as "absorption" modulation. The version of Figure 6–4b is sometimes called "loop" modulation.

The elementary methods of modulation described are workable and actually were used to obtain modulation in the early days of radiotelephony. They have many shortcomings, however, and are never found in present-day equipment because of the vastly superior methods of modulation now available. Among the shortcomings of these methods of modulation are:

1. The percentage of modulation obtainable is low.
2. They are limited to use in transmitters of extremely low output because of heating of the microphone.
3. They are limited to the use of the carbon microphone which, as it is connected in the r-f circuit, must employ very short leads and be located directly at the transmitter.

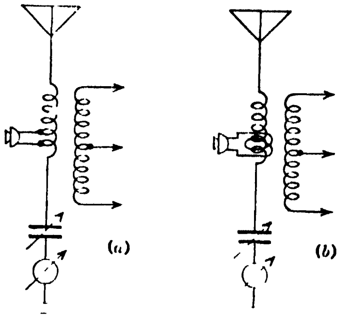

Fig. 6–4. Absorption modulation. (a) Conductive coupling, (b) inductive coupling.

6–3. Modulation Systems—The elementary systems of modulation were very poor with regard to electrical efficiency because they operated on the power output of the high-frequency oscillator or amplifier. This method of operation can be compared to a loaded d-c generator whose output voltage is varied by means of a variable resistor in the output circuit of the generator. A better way to accomplish the same control is to vary one of the factors which govern the magnitude of the generated voltage.

In the case of a high-frequency generator using an oscillating vacuum tube, it is extremely undesirable to modulate the oscillating tube, as the frequency of oscillation is affected by the modulation. Because of this, it is necessary to modulate an r-f amplifier tube, the oscillator only supplying r-f excitation to one of the amplifier stages. The oscillator is usually isolated from the modulated r-f amplifier stage by several "buffer" stages.

A triode r-f amplifier stage can be modulated by varying its (1) grid bias voltage; (2) d-c plate voltage; (3) grid excitation voltage. These methods form the basis of two general systems of amplitude modulation, namely; grid modulation and plate modulation which are used extensively in radiotelephone transmitters. Variations of these methods are employed in transmitters where the modulated amplifier is a tetrode or a pentode.

6–4. Form of Modulated Wave—When an r-f carrier wave is amplitude modulated, its amplitude is varied in much the same manner as the d-c carrier current in a wire telephone circuit. The form of the r-f envelope when modulated by a single audio frequency is illustrated in Figure 6–5. It will be noted that the amplitude of the carrier current is symmetrical above and below the zero line since both the positive and negative sides of the r-f cycle are affected equally by the modulating signal.

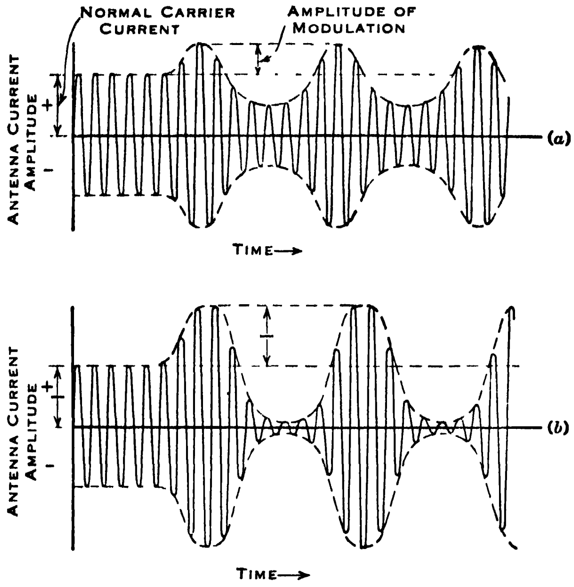

FIG. 6–5. Wave with sinsoidal modulation. (a) 50 percent modulation, (b) approximately 95 percent modulation.

The degree of amplitude variation in a modulated wave is often expressed in terms of the *degree of modulation*, symbolized *m*. In terms of *m*, 1.0 equals complete or 100-percent modulation, 0.5 equals 50-percent modulation, etc. The term *m* will be encountered frequently later in this chapter.

6–5. Side Bands in Amplitude Modulation—Amplitude modulation is a process of combining an r-f carrier and an audio (or video) modulating signal. Because of the heterodyning action which results, with the subsequent "beat frequencies," there are produced new frequencies equal to the sum and difference of the radio and audio frequencies involved. These new frequencies are known as "side frequencies" or "side bands."

As an example, let us assume that a carrier frequency of 600 kc is modulated by an audio frequency of 5000 cycles (5 kc). In addition to the carrier frequency of 600 kc, two new frequencies will now be present; an upper side frequency of 600 plus 5, or 605 kc, and a lower side frequency of 600 minus 5, or 595 kc.

The width of the band necessary to transmit such a signal will be 10 kc, the difference between the upper side frequency and the lower side frequency. Ordinarily modulation is not composed of a single-frequency sine wave but of many complex frequencies of speech and music, so that we have not a pair of side frequencies, but two "side bands" of frequencies, each as wide as the band of audio frequencies being transmitted. Such a modulated wave occupies a channel, or band of frequencies, the width of the channel being two times the highest modulating frequency.

Side bands are present only when modulation is taking place, the frequency and amplitude of the side bands being determined by the characteristics of the modulating signal. The intelligence being conveyed in the modulated wave is contained in the side bands and not in the carrier wave. It can therefore be seen that the maximum effectiveness will be obtained when as much power as possible is put into the side bands. This is accomplished when the modulation is as great as possible, that is, when the amplitude of the carrier is reduced completely to zero during the negative swing of the modulation cycle.

When both side bands are radiated, as is usually the case, the system is referred to as *double side-band transmission*. It is possible to attenuate one side band and thus reduce the bandwidth necessary for transmission to that of the highest modulation frequency employed; in the example given, this would be 5 kc. Such *Single side-band transmission* is used in commercial point-to-point radiotelephony (see Section 18 of this chapter).

6–6. Power in Side Bands—The percentage of the total power which appears in the side bands, assuming sinusoidal waveform, can be calculated from the formula:

$$P_{sb} = \frac{m^2}{2 + m^2} \times 100$$

therefore, when the carrier is completely or 100-percent modulated, the power in the side bands will be:

$$P_{sb} = \frac{1^2}{2 + 1^2} \times 100 = 33\tfrac{1}{3}\%$$

From this it can be seen that in a completely modulated carrier one-third of the total radiated power is contained in the side bands, while two-thirds of the power remains in the carrier.

When the modulation is 50 percent, the power in the side bands will be:

$$P_{sb} = \frac{0.5^2}{2 + 0.5^2} \times 100 = 11.1\%$$

or only ⅙ of the total radiated power.

The power in an a-c sine wave varies as the square of its amplitude. Since the amplitude of a modulated carrier is $1 + m$ times the amplitude of the unmodulated carrier, the ratio of the peak power of the modulated carrier to unmodulated carrier can be found by squaring $1 + m$ or, as an equation:

$$\frac{P_m}{P_c} = (1 + m)^2$$

In 100-percent modulation, m equals 1; hence the peak power will be two squared or four times the unmodulated carrier power. Therefore, during peaks of complete modulation, the modulated stage must produce output power peaks four times as great as the unmodulated carrier power.

6–7. Plate-Modulated Class C Triode Amplifiers—Plate modulation employs a conventional Class C r-f amplifier adjusted in such a manner that the tube's output voltage will be proportional to the applied plate voltage. The plate voltage is then varied in accordance with the desired modulation. This variation of plate voltage is accomplished by coupling an audio power amplifier, known as the modulator, to the d-c plate supply circuit of the modulated tube in such a manner that the audio voltage is superimposed on the d-c supply voltage.

The most widely used system of plate modulation employs a transformer, known as the modulation transformer, to combine the a-f power generated in the modulator with the d-c supply to the modulated stage. This method of modulation is illustrated in Figure 6–6. The modulator stage may employ tubes operating as Class A, Class AB, or Class B amplifiers. This same arrangement may be used with a single-ended modulator, rather than the push-pull arrangement illustrated; however, in this case, it would be necessary to operate the modulator tube as a Class A amplifier. Inasmuch as the audio output power from a single modulator tube operated as a Class A amplifier is relatively small, such an arrangement would be restricted to use in low-power transmitters.

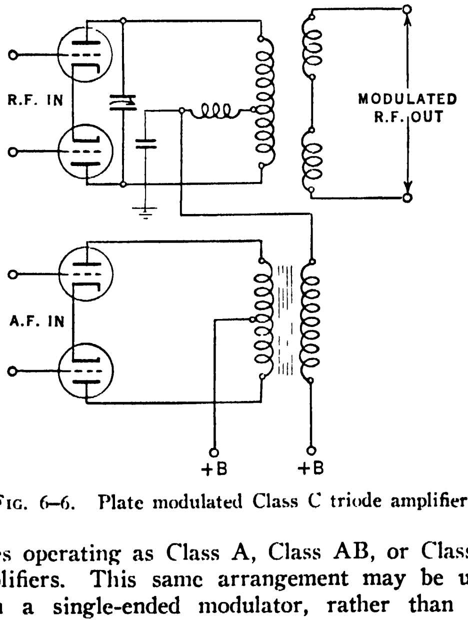

FIG. 6–6. Plate modulated Class C triode amplifier.

To obtain 100-percent modulation with the arrangement shown in Figure 6–6, it is necessary that the output power from the modulator tubes and the turns ratio of the modulation transformer be so chosen that the voltage supplied to the modulated r-f amplifier will vary between zero and twice the normal d-c supply voltage.

6–7a. Modulation Power Requirements—Complete, or 100-percent, plate modulation requires audio power equal to one-half the d-c plate input of the tube being modulated.[1] This can be shown as follows: During modulation, the alternating current from the modulators is superimposed on the direct plate current of the tube being modulated. This is shown in Figure 6–7, where I_b is the steady direct current without modulation and $I_{\max}$ the variation of plate current during modulation. This is to say $I_{\max}$ is the peak value of the alternating current, and, if we make the assumption of sinusoidal wave form, the effective value of alternating current is $0.707\ I_{\max}$. The effective value of the combined steady direct current with the alternating current superimposed is:

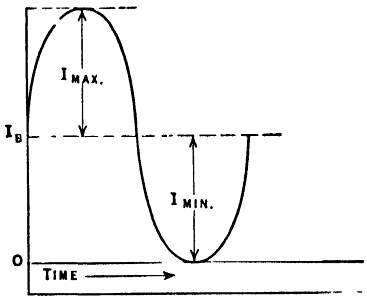

FIG. 6–7. Diagram showing instantaneous value of plate current during modulation.

$$I_{\text{eff}} = \sqrt{I_b^2 + (0.707 I_{\max})^2}$$

Since power varies as the square of the current, the power represented by the combined currents may be calculated from the formula:

$$P = (I_b^2 + \tfrac{1}{2} I^2_{\max}) R_l$$

where R_l = the resistance through which the modulated current flows. During periods of no modulation, the power input to the plate of the modulated stage is:

$$P = I_b^2 R_l$$

which also may be stated

$$P = E_b \times I_b$$

Therefore

$$E_b \times I_b = I_b^2 \times R_l$$

$$R_l = \frac{E_b}{I_b}$$

---

[1] It is assumed that the modulation is sinusoidal, otherwise the stated power ratio does not hold.

Since the d-c portion of the plate input power is constant, the power required to modulate the plate current to $(I_{\max}/I_b)$ percent is $(I^2_{\max}R_l/2)$. When the plate current is completely modulated (100 percent), $I_{\max}$ equals I_b, and the a-c power required is found to be 50 percent of the d-c plate input power.

The value R_l mentioned above is known as the modulating impedance and represents the load into which the modulator operates. Since it is necessary to operate audio amplifiers, including modulators, into a load of the correct value in order to obtain maximum output with low distortion, it is apparent that R_l must be chosen to suit the requirements of the audio output stage, or modulator.

The load presented to the modulator is equal to $\frac{E_b}{I_p}$ where E_b is the d-c plate voltage and I_p the d-c plate current (in amperes) of the r-f amplifier.

The load presented to the modulator may be adjusted to some extent by adjusting the plate voltage and plate current of the modulated tube, but, more commonly, it is accomplished by a proper choice of the ratio of primary to secondary turns in the modulation transformer coupling the modulator tubes and the plate circuit of the r-f tube. This transformer, which is a conventional audio output transformer, is sometimes designed to carry the direct current of the modulated tube through its secondary winding, in which case it is provided with a large core with an air gap, as are all iron-core devices carrying both a.c. and d.c.

It is interesting to compute the percentage of modulation obtainable when the audio power available for modulation is less than 50 percent of the d-c plate input of the modulated stage, that is, less than that required to accomplish 100-percent modulation.

Audio power is proportional to the square of the percentage of modulation (up to 100 percent) or:

$$m^2 = k \times P_{\text{audio}}$$

Put into words, the above equation means: "The degree of modulation squared is proportional to the modulating power." k indicates proportionality: its value need not be known as it cancels out during the calculation, as will be shown. The above equation also could have been written

$$m = \sqrt{k(P_{\text{audio}})}$$

which in words means: "The degree of modulation is proportional to the square root of the audio power."

The use of these equations will be illustrated by means of an example in which the d-c power input is assumed to be 800 watts, which we know can be fully modulated by 400 watts of audio power if the modulation is sinusoidal. Our problem is: If we have but 200 watts of audio power, what degree of modulation can be obtained?

$$\text{For 400 watts: } m_1^2 = k\ (400)$$
$$\text{For 200 watts: } m_2^2 = k\ (200)$$

Dividing the first equation by the second:

$$m_1^2/m_2^2 = k\ (400)/k\ (200)$$

At this point k cancels out and as m_1 is known to be 1, we have:

$$1/m_2^2 = 400/200 = 2$$

inverting

$$m_2^2 = 1/2$$

therefore

$$m_2 = \sqrt{1/2} = 0.707$$

This is equivalent to 70.7 percent modulation.

6-7b. Antenna Current—It is possible (although not recommended, see page 163) to make a calculation of the percentage of modulation from the rise in antenna current when the transmitter is modulated by a *sustained* audio sine wave. If the unmodulated antenna current is denoted by I and the fractional increase during modulation by ΔI then

$$m = \sqrt{(2\Delta I)(2 + \Delta I)}$$

For example, if the antenna current during periods of no modulation is 4 amp, and during modulation it increases to 4.9 amp, the increase would be 22.5 percent. Substituting:

$$m = \sqrt{(2 \times 0.225)(2 + 0.225)} = \sqrt{0.450 \times 2.225}$$
$$m = 1$$
$$m = 1 \times 100 = 100\%$$

If the antenna current had increased only 10 percent, then:

$$m = \sqrt{2 \times 0.1(2 + 0.1)} = \sqrt{0.42}$$
$$m = 0.65$$
$$m = 0.65 \times 100 = 65\%$$

It is convenient to calculate the percentage ot modulation by the use of a current-squared instrument coupled to the modulated stage. Full-scale deflection of the Weston 301 thermo-galvanometer requires a current of 115 ma, the scale being divided into 100 equal divisions. The current for any scale deflection may be found by the following relation:

$$I = 11.5\sqrt{D}$$

where D = the deflection

If the meter is coupled to the transmitter so that a reading of 40 scale divisions is obtained without modulation, from the above equation the current at this deflection will be 72.77 ma. If the transmitter is now modulated and the pointer reads 60 scale divisions, the current will be 89.08 ma. The ratio of these two readings is 1.226, which is that required for 100-percent modulation.

The percentage of modulation may be calculated from

$$m = \sqrt{2\left(\frac{I_m^2}{I_c^2} - 1\right)}$$

and since the scale divisions are already current-squared values,

$$m = \sqrt{2\left(\frac{60}{40} - 1\right)} = \sqrt{2 \times 0.5} = \sqrt{1}$$

$$m = 1$$

$$m = 1 \times 100 = 100\%$$

It will be shown later (Section 6–12) that the measurement of modulation by either of the two methods which have just been described is of little practical value, since the relative values of the positive and negative peaks cannot be determined and since there are other sources of inaccuracy.

6–7c. Antenna Power—When the carrier is unmodulated, the power in the antenna is:

$$P_c = I_t^2 R$$

where P_c = power in unmodulated carrier
I_t = unmodulated antenna current
R = the resistance of the antenna at the point where the current is read

The increased output power during modulation appears in the side-band frequencies and it is through the medium of these new frequencies that speech, music, or other forms of intelligence are transmitted. Since the received signal depends, in general, upon the variations in the amplitude of the wave, it is obvious that the most efficient use of the carrier wave is accomplished when it is completely or 100 percent modulated.

6–7d. Modulation with Complex Wave Forms—In the foregoing discussion of modulating power it has been assumed that the modulating voltage was a single-frequency sine wave, therefore the peak value was 1.4 times the effective value and overmodulation became possible when the audio power exceeded 50 percent of the d-c input to the modulated stage. This does not hold true when dealing with complex wave forms such as are encountered in both speech and music, and it must *never* be assumed that overmodulation cannot occur merely because the audio system is of the correct size or smaller.

6–7e. Circuit Relationships During Modulation—To provide a convenient reference for showing the relationship of the various factors thus far discussed as a function of the percentage of *sinusoidal* modulation, the following table has been prepared:

Percent Modulation	Percent Increase in Antenna Current	Percent Increase in Current Squared Galvanometer	Relative Audio Power Required	Percent of Power Radiated in Side Bands	Ratio Peak Power to Unmodulated Power
100	22.5	50.0	100.0	33.3	4.0
90	18.5	40.5	81.0	28.8	3.6
80	14.9	32.0	64.0	24.2	3.2
70	11.6	24.5	49.0	19.7	2.9
60	8.6	18.0	36.0	15.3	2.7
50	6.1	12.5	25.0	11.1	2.3
40	3.9	8.0	16.0	7.4	2.0
30	2.2	4.5	9.0	4.3	1.7
20	1.0	2.0	4.0	2.0	1.4
10	.3	.5	1.0	.5	1.2
0	0	0	0	0	1.0

If the carrier is modulated by an audio frequency, the antenna current will increase since additional power is developed by the amplifier tube delivering power to the antenna. The power in the antenna also increases and can be calculated from the following formula, which applies to sinusoidal modulation:

$$P_m = I_t^2 R \times \frac{2 + m^2}{2}$$

where P_m = power in modulated carrier
m = degree of modulation

If the carrier is completely modulated sinusoidally, m is equal to 1, the power during modulation is increased 1.5 times, and the antenna ammeter (which reads the effective value of the current and not the power) increases in reading to $\sqrt{1.5}$ or 1.226 times its reading with no modulation.

The most striking point shown by this table is that even with 100-percent modulation, the radiated power still consists largely of "carrier" which contains no intelligence frequencies and appears to constitute a mere loss of power. In fact, the steady carrier component, in theory, need not be radiated as it is possible to accomplish reception provided that a correctly adjusted carrier is supplied at the receiver. The strength of the received signal in such a case depends entirely upon the power radiated in the form of side bands. In commercial transoceanic telephony one side band as well as the carrier frequently is suppressed, the carrier frequency being subsequently restored at the receiver by a suitable radio-frequency oscillator. A large power saving at the transmitter results, but unfortunately this type of receiver is highly specialized, and hence is not available for general public use.

6–8. Choke-coupled (Heising) Plate Modulation—Another method of plate modulation, sometimes known as the "Heising" or "constant-current" system of modulation, employs choke coupling between the modulator tube and modulated amplifier. The d-c plate power for both the modulator and the modulated amplifier, which is usually supplied from a common source, flows through a large inductor which provides a high impedance to audio frequencies.

The modulator operates as a Class A audio amplifier with its output power being superimposed upon the d-c supply voltage to the r-f amplifier. The load into which the modulator operates is the plate circuit of the r-f amplifier. As with plate modulation employing transformer coupling, if 100-percent modulation is to be obtained, the audio output of the modulator must be capable of driving the d-c voltage applied to the r-f amplifier from zero to twice its normal unmodulated value.

The original Heising circuit arrangement is shown in Figure 6–8. This circuit arrangement is not capable of 100-percent modulation, nor was it intended to provide it, for this circuit originated in the early days of radiotelephony when the tube which was modulated was the r-f oscillator.

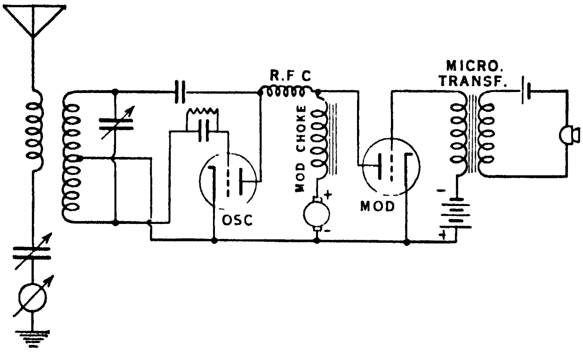

Fig. 6–8. The original Heising system of plate modulation, employing choke coupling between the modulator and modulated oscillator. The circuit shown, wherein the oscillator is modulated, is seldom used today.

With the appearance of more numerous stations and more selective receivers, it became essential to abandon modulation of the oscillator because of the rapid frequency waver which resulted during modulation. This "dynamic instability" has the practical effect of making the signal very broad and hence producing inordinate interference. To avoid this, the modern radiophone transmitter, except at extremely high frequencies, does not modulate the oscillator, nor even a tube adjacent to the oscillator. Thus the simplest r-f system capable of proper modulation by present standards consists of a well-stabilized oscillator (usually crystal-controlled and further stabilized by temperature control and separate power supply), which feeds a "buffer" amplifier, after which comes the r-f amplifier stage to be modulated. More intermediate stages are common in transmitters of considerable power, either to raise the power level or to provide additional oscillator protection or, in some cases, to double or otherwise raise the frequency before the modulated tube is reached.

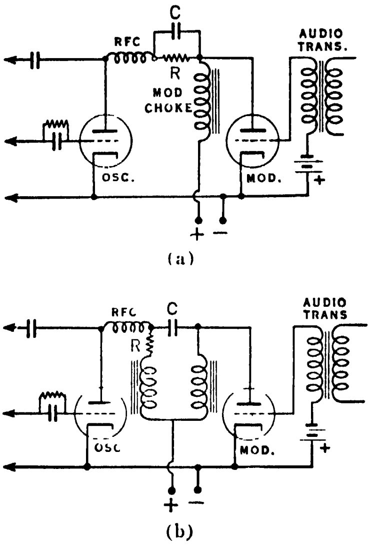

Fig. 6–9. Two methods of obtaining 100 percent modulation with Heising modulation. (a) employs a by-passed voltage-dropping resistor in the plate circuit of the r-f tube; (b) employs a dual-winding choke coil, one winding of which feeds the modulator tube, the other the r-f tube. A voltage dropping resistor is included in the winding feeding the r-f tube.

The apparently onerous complication of the r-f system by these additions is justified by the lessening of interference and by the great increase in efficiency. The reason for the greater efficiency is that, when modulating an oscillator, modulation greater than 50 percent (an optimistic estimate) is not possible with acceptable fidelity. From the table of Section 6–7e it can be deduced that only about 11 percent of the power radiated is in the form of side bands, the useful part of radiation.

Modifications of the original Heising system of modulation have been devised whereby it is possible to attain 100-percent modulation, assuming, of course, that an r-f amplifier stage is modulated. Two such arrangements are shown in Figure 6–9, both circuits being connected in such a manner that the r-f amplifier operates at a lower d-c plate voltage than the modulator tube.

The simpler arrangement is that shown in Figure 6–9a, which employs a voltage-dropping resistor in the plate circuit of the r-f amplifier tube. To prevent a loss of audio power in this resistor, there is provided a large by-pass condenser, the impedance of which must be low compared to the value of the dropping resistor used.

The circuit of Figure 6–9b employs a dual-winding choke coil for coupling, one winding feeding power to the modulator, the other to the r-f amplifier. A voltage-dropping resistor is included in series with the winding that feeds power to the r-f amplifier. The advantages of such an arrangement lie in the fact that such a dual-winding inductor is usually less expensive than a single-winding inductor of larger current-carrying capacity and, since both windings are on the same iron core, it is possible to choose the direction of winding to balance out magnetic core saturation due to the direct current flowing through the windings.

It has been previously stated that when an audio power amplifier is employed as a modulator, the load resistance is an important consideration. Consider a Class A audio modulator in a choke-coupled modulation system in which 100-percent modulation is accomplished by providing a dropping resistor in series with the plate supply to the modulated r-f amplifier.

The load or impedance into which the modulator works is determined by dividing the d-c plate voltage of the r-f amplifier by its plate current and it should approximate the modulator's rated load impedance. Exact agreement is not essential in low-impedance Class A audio tubes. Assume the modulator is operating with 1000 volts at 60 ma plate current and that the rated power output as a Class A amplifier is 35 watts for a load resistance of 3500 ohms. The plate voltage and plate current of the modulated stage necessary to provide the desired load impedance to the modulator can be determined by the application of Ohm's law as follows:

$$E_b = \frac{P}{I_b} \quad \text{and} \quad I_b = \sqrt{\frac{P}{R_L}}$$

where E_b = d-c voltage on r-f amplifier
I_b = d-c current in amperes to r-f amplifier
P = product of E_b and I_b and twice modulator output power in watts
R_L = load resistance for modulator in ohms

Solving for I_b by substituting the known values:

$$I_b = \sqrt{\frac{2(35)}{3500}} = 0.140 \text{ amp} = 140 \text{ ma}$$

$$\text{and} \quad E_b = \frac{2(35)}{0.140} = 500 \text{ volts}$$

The voltage drop between the modulator and r-f amplifier is calculated by subtracting the applied voltage on the former from that required on the r f amplifier, or 1000 − 500 = 500 volts. The total d-c current of the r-f amplifier will flow through the resistor so its value is also calculated from Ohm's law.

$$R = \frac{500}{0.140} = 3571 \text{ ohms}$$

The heat dissipation is I^2R, or 70 watts. A 200-watt resistor will provide an adequate margin of safety.

Figure 6–10 shows a schematic diagram of a portion of the Western Electric Type 105–C telephone transmitter and is introduced at this point to illustrate a commercial application of the arrangement in Figure 6–9b. This circuit falls under the classification of low-level modulation since the output of the modulated stage is further amplified before being applied to the transmitting antenna. The second intermediate amplifier is the modulated stage in this transmitter. Deep modulation, approaching 100 percent, is obtained in this stage by using the double choke arrangement of Figure 6–9b. A single 250-watt tube is used as the modulator to

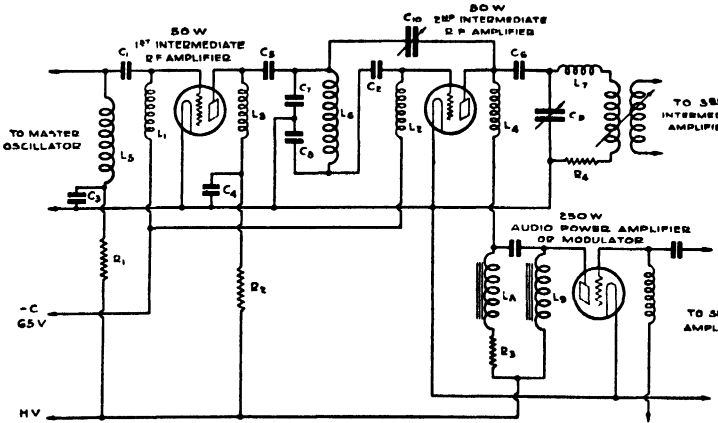

Fig. 6–10. Schematic diagram showing circuit of Figure 6–9b used in a Western Electric transmitter.

modulate the 50-watt second intermediate r-f amplifier tube instead of using two or three tubes of the 50-watt size. This design provides a wide margin of safety with regard to heat dissipation in the modulator and permits operation of the second intermediate amplifier at its full power output and plate voltage rating. If several smaller tubes were used in the modulator, it would. be necessary to operate the intermediate amplifier at a plate voltage below normal and thus limit its power output.

The function of other circuit components shown in Figure 6–10 are: The r-f grid chokes L_1 and L_2 serve to keep r-f currents from backing into the bias supply. The r-f plate chokes L_3 and L_4 serve a similar function for the plate supply. C_1 and C_2 are grid-isolating condensers and are used for the purpose of keeping the bias voltage from being applied to the tank circuit inductors L_5 and L_6. C_3 and C_4 are by-pass condensers. C_5 and C_6 are plate-blocking condensers. C_7 and C_8 serve as tank-tuning condensers for the tank circuit of the first intermediate r-f amplifier. C_9 serves a similar duty for the tank circuit of the second intermediate r-f amplifier, the tank inductor being L_7. C_{10} is the neutralizing condenser for the second r-f amplifier. The resistors R_1, R_2, R_3 are used for the purpose of reducing the plate supply voltage of 1600 volts to 1000 volts, the rated value for the 50-watt tubes. The iron-core inductors L_8 and L_9, together with the condenser C and resistor R_3, form the circuit for obtaining deep modulation. In this and many other high-power radiotelephone equipments, the modulated tube does not feed the antenna but is followed by a Class B r-f stage or else a Doherty r-f stage. The resistor R_4 serves as a loading resistance for the tank circuit of the second (modulated Class C) r-f amplifier. Its function is to provide a more constant load for this stage to offset the variable load presented by the third (Class B or Doherty) r-f amplifier. This loading of the modulated tube is essential because low distortion plate modulation can be obtained only under constant load conditions. By making the variable load (produced by variation in grid current of the Class B or Doherty r-f amplifier during modulation) small in comparison to the fixed resistance load, satisfactory operation is obtained.

6–9. Plate Modulation of Tetrodes and Pentodes—When a tetrode (or a pentode connected as a tetrode) is to be plate-modulated, there is a tendency toward distortion at the higher modulation levels. This distortion is largely avoided by supplying the screen current through a series resistor from the unmodulated plate supply, thus introducing a tendency toward self-modulation of the screen which must not have a large by-pass condenser. In the case of a pentode, however, the series screen-resistor must derive its voltage from the modulated plate supply for lowest distortion, hence R_L and the audio power demand must be figured on the basis of the current drawn by both plate and screen, using the full plate supply voltage as the other factor. Modulation of the screen alone is intermediate between these systems and the suppressor grid modulation system described in Section 6–10b with regard to both audio requirements and carrier power.

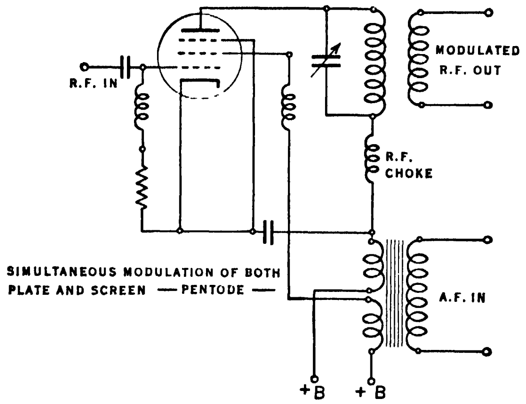

Fig. 6–11. Pentode Class C amplifier with simultaneous modulation of screen grid and plate.

6–10. Grid-bias Modulation—In this system of amplitude modulation the a-f modulating voltage is applied to the grid of an r-f amplifier stage of the transmitter. Consider the circuit of Figure 6–12. The secondary of an a-f transformer is connected directly to the electrical center of the grid circuit of a push-pull r-f amplifier. One terminal of the secondary of the a-f transformer is returned to the negative bias supply, and adequate filtering is provided to prevent radio- or audio-frequency currents from feeding back into the bias supply. The center of the grid inductance is brought to ground through condensers that do not have sufficient capacitance to by-pass appreciably the audio-modulating frequencies. This method of grid-bias modulation is employed by the Western Electric Company in several of their transmitters. It will be noted that, although the grids are out of phase with respect to the r-f excitation voltage, the a-f voltages operate as if the grids were in parallel since the grid inductance offers no reactance to the audio frequencies.

Referring to rule 3.52 of the FCC, it will be noted that the operating power of a broadcasting station is determined by indirect measurement of the plate input power of the final r-f stage. The plate voltage is multiplied by the total plate current of the last r-f stage, and this result is multiplied by an efficiency factor. When stations use grid-bias modulation in the last r-f stage, the efficiency factor is 0.25 as compared to 0.70 for plate modulation. The efficiency is low because the r-f excitation must be greatly reduced when such modulation is em-

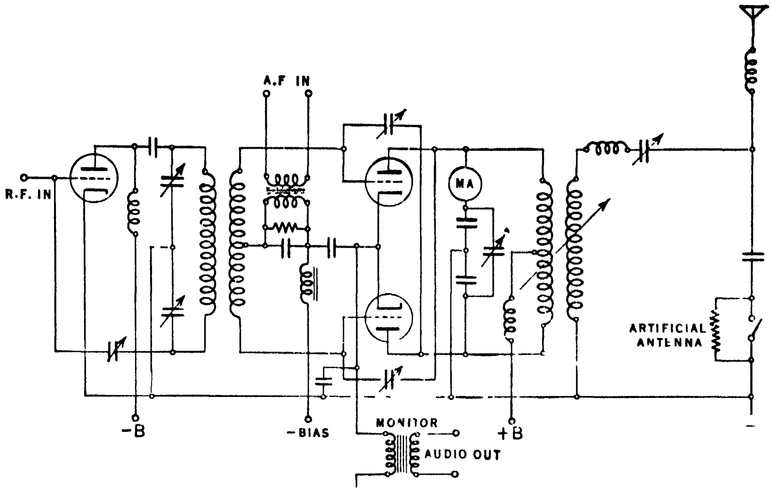

FIG. 6–12. Grid bias modulation as employed in a Western Electric transmitter.

ployed. The installed tube capacity must be ten times the carrier power. The W.E. type 12–A transmitter, employing grid-bias modulation in the final stage, uses two 500-watt tubes in push-pull to provide a 100-watt carrier. Similarly, the FCC rates the power of the W.E. 212–E tube at 250 watts when used as a plate-modulated r-f amplifier, whereas the same tube, when modulated by grid bias, is given a rating of only 50 watts.

One advantage of grid-bias modulation is that the audio level necessary to accomplish complete modulation is very low, thus obviating the necessity of employing large a-f stages and their associated power supplies. The W.E. 12–A transmitter (100 watts output, 455 watts input) requires only 0.6 watts of audio power to provide 100-percent modulation.

On the other hand, 100 watts of carrier power can be produced with plate modulation using a pair of the much smaller 50-watt W.E. 211–D tubes, and since the efficiency of plate-modulated tubes is greater (70 percent) it is found that the d-c input for an output of 100 watts is about 143 watts. The audio demand, therefore, is $143/2 = 73$ watts, which may be supplied by various Class B tube combinations whose power demand varies from 25 or 30 watts (nonmodulating) to 150 watts (full modulation). The total power demand accordingly varies from 180 to 300 watts. Although the cost of the larger tubes used in grid-bias modulation is saved in plate modulation, the additional audio stages required partly cancels this saving.

Referring to Figure 6–13, the d-c grid-bias voltage is shown adjusted to approximately one and one-half times cutoff (the value necessary to reduce the plate current to zero) R-f excitation is then applied until the required unmodulated output is obtained. A-f voltages then vary the effective bias in such a manner that the peak r-f grid voltage is varied between zero bias and cutoff and a completely modulated r-f output is obtained. (The r-f peak voltage equals approximately two-thirds bias; the a-f peak voltage for full modulation equals one-third bias; hence the greatest momentary sum of their two a-c voltages equals the total bias.) In this particular transmitter, sufficient r-f voltage is applied to the grids just to reach the point where they become positive and grid current flows on the peaks of modulation. During modulation when the unmodulated carrier is adjusted to 100 watts, 400 watts of peak power is delivered to the antenna. The maximum plate efficiency is 50 percent and the unmodulated efficiency one-half of this value, or 25 percent, corresponding to the efficiency factor authorized by the FCC for broadcast transmitters employing grid-bias modulation in the r-f amplifier stage feeding the antenna. It is apparent that in order to obtain a 100 watt carrier, 300 watts are dissipated by the tube plate when there is no modulation, the input being 400 watts at such times. During modulation the efficiency improves and the plate cools off. Thus it may be said that a grid-bias-modulated tube operates with fixed plate input and variable plate efficiency.

6–10a. Grid-bias Modulation at Higher Efficiency—In the grid-modulation system described above, very little power is taken from either the audio or r-f grid driving sources because the grid always operates in the negative region. It will be noted that the "carrier" condition compares with ordinary Class A audio work as to both grid bias and efficiency, while during modulation the system works near the positive grid region at the efficiencies associated with Class AB audio work. The logical conclusion is that higher efficiency may be obtained by swinging into the positive grid region, provided

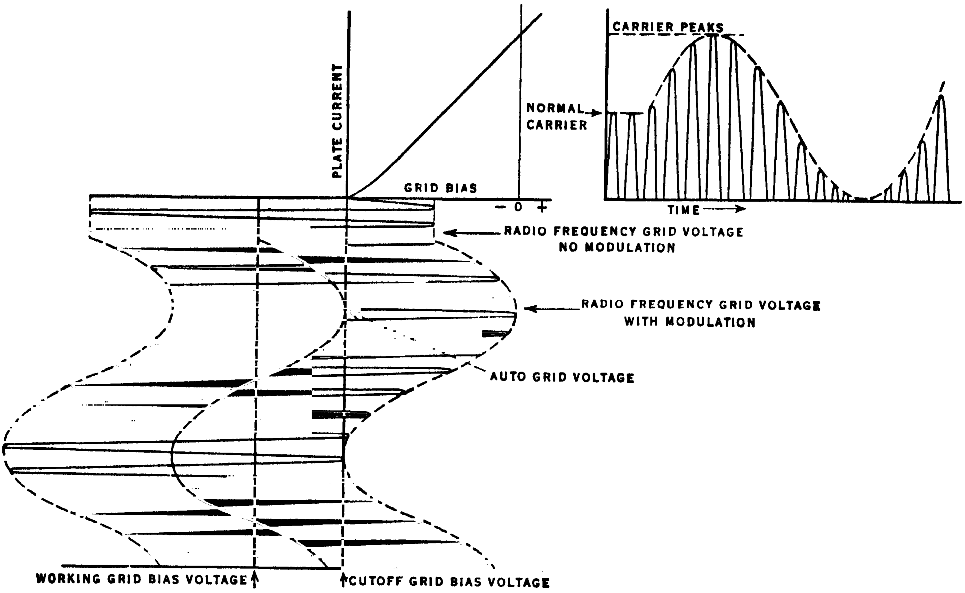

FIG. 6–13. Operating characteristics of grid-modulated radio frequency amplifier.

that the consequent distortion can be eliminated as successfully as in the Class B audio push-pull amplifier. Experiments along this line have been conducted and described in radio literature. In one system, described by J. N. A. Hawkins, distortion at high modulation levels is suppressed by the use of compound grid bias, one portion of which is fixed, while the other is derived from a cathode resistor and is varied in the proper manner to effect some correction.

In the case of a grid-modulated pentode, the grid-modulation method may be employed in the negative grid region only if very small output is acceptable. Such tubes are accordingly grid-modulated (usually) with r-f and audio voltages about twice as great (relative to the bias) as stated in the parenthetical note in Section 6–10. Under these conditions modulation acceptable for speech transmission can be obtained with a plate-circuit efficiency around 33 percent for the unmodulated carrier, that is, about one-half the carrier power provided by the same tube with plate and screen modulation. This value is about 3 times the carrier power obtainable with negative grid operation. Although in this case the control grid does demand some power from both the r-f and audio sources, the demand is moderate because of the ease with which a pentode is driven for moderate positive grid excursions.

6–10b. Suppressor Grid Modulation—The circuit arrangement shown in Figure 6–14 is used to modulate pentode r-f amplifiers by varying the voltage of the suppressor grid. This method of modulation falls into the same class as the "higher efficiency" grid-bias modulation just discussed. Approximately the same degree of efficiency is obtained, and the tube operates with variable efficiency. The adjustment is somewhat easier than in control grid modulation, and the distortion on positive modulation peaks tends to be somewhat higher. This form of modulation is encountered principally in amateur and experimental transmitters intended primarily for telegraphy and provided with the simplest possible auxiliary modulation equipment.

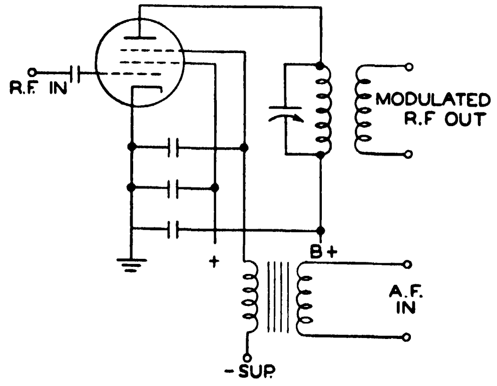

FIG. 6–14. Suppressor grid modulation of pentode.

It must be understood that for either suppressor grid modulation or control grid modulation it is necessary to employ different electrode voltages from those used when the same pentode acts as a plate-screen modulater or as a telegraph amplifier. The correct values are given in tube data supplied by the manufacturer of the tube.

6–11. Series Modulation—Although its use has been confined generally to European stations, the principles of series modulation have been known for years. Tests have proved that satisfactory frequency response and other performance characteristics are obtainable at both high and low powers. The British Marconi Company has employed series modulation, since 1933, in a transmitter having an output of 30 kw which, in turn, operates into a 300-kw Class B linear amplifier. With this linear amplifier operating at 30-percent efficiency, it was found possible to modulate up to 90 percent with a distortion factor of less than 4 percent.

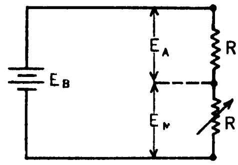

FIG. 6–15. Equivalent circuit of series modulation system.

Since the use of a modulation choke or transformer is not required in series modulation, the circuit is capable of uniform frequency response over a wide band of frequencies. This feature may encourage the use of series modulation in television transmitters as they are required to transmit a very wide band of frequencies with a minimum of frequency discrimination. Series modulation found application during World War II in radio "countermeasures" equipment. It was used to modulate magnetron tubes in transmitters requiring the transmission of a wide band of frequencies for the purpose of "jamming."

The equivalent circuit of a series modulation system is shown in Figure 6–15, and an elementary circuit showing the tube arrangement is shown in Figure 6–16. It will be noted that the filament circuit of the modulated Class C amplifier is above ground potential. If desired, the modulator can be placed above ground potential and the filament of the r-f amplifier grounded; however, the former permits a more convenient arrangement of grid bias. The capacitance of the r-f by-pass condenser, C, must be very small, otherwise high modulation frequencies will be shunted to ground.

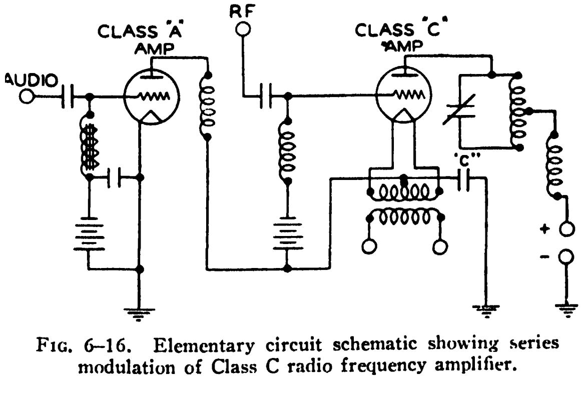

FIG. 6–16. Elementary circuit schematic showing series modulation of Class C radio frequency amplifier.

Referring to Figure 6–15, the plate supply E_b has connected in series with it two resistances, R_a corresponding to the Class C r-f amplifier of Figure 6–16 and R_m variable in value and corresponding to the Class A modulator. If it is assumed that R_a and R_m are equal, the plate supply voltage E_b will divide equally across them ($E_a = E_m$). Now if R_m is varied in value from zero to infinity, the voltage across the fixed resistance R_a (modulated amplifier) will vary from its normal value (unmodulated carrier) to twice that value and to zero, therefore accomplishing complete modulation of the r-f amplifier.

In practice, it is not possible to employ tubes having the ideal ohmic resistance required to reduce the modulator resistance to zero or with a symmetrical grid swing to make its resistance infinite. However, by judicious choice of modulator tube and by correct adjustment of modulator grid bias so that with no modulation the voltage across the modulator is higher than that of the Class C amplifier, it is possible to obtain a peak voltage on the latter of twice the carrier value and also reduce it nearly to zero, thereby accomplishing a very high percentage of modulation.

The relatively high plate supply voltage required for series modulation is no longer a serious difficulty since generators have largely been replaced by rectifier-filter systems, but the series arrangement of tubes and the high voltage itself continue to make the system comparatively costly and somewhat more dangerous to equipment and personnel.

6–12. Uncertainty of Measuring Modulation by Antenna Current Increase—When an r-f carrier is modulated, the rms output is increased. As the amount of increase depends upon the percentage of modulation (see table in Section 6–7c), it is theoretically possible to measure the modulation percentage by noting the rise in antenna current. Experience has shown that this is too inaccurate to be of any practical value. There are two reasons why this is so.

In measuring modulation, we are concerned with *peak* values (instead of average or rms values) because it is the peaks which may overload the transmitter and cause distortion. *If the modulation is a single pure tone,* there is a fixed relation between the peak value and the rms value. For such modulation the antenna current should increase 22½ percent when the peaks of modulation are 100 percent. Unfortunately, the modulation is usually ***not*** a single pure tone (except when the transmitter is being tested with an audio signal generator) but is very complex. ***For complex waves such as occur in speech and music there is no fixed relation between the rms value and the peaks.*** This makes it impossible to determine the value of the peaks by reading the antenna ammeter which indicates the rms value. The increase in antenna current during modulation is a measure of modulation only to this extent—no increase indicates a low percentage of modulation; a slight increase of perhaps 5 to 10 percent indicates fairly high modulation; and an increase of more than 15 percent is almost certain to mean overmodulation. These are general statements and by no means constitute a measurement.

The second reason why the antenna current is an unreliable indicator of modulation is that it is difficult to determine how much of the antenna current change is properly caused by the modulation. Unless the transmitter has absolutely no distortion, the positive and negative modulation peaks will not be equal.[2] If the positive peaks are greater than the negative peaks, there will be a greater tendency for an antenna current increase, and the change will be greater than would be computed for the degree of modulation present. On the other hand, if the negative peaks are the greater, the antenna current will have less tendency to rise, and the change will not be as large as would be expected. In fact, in extreme cases the antenna current will not rise, or may even dip during modulation. Although such an extreme occurs only when the distortion is quite noticeable, even an unnoticeably small amount of distortion can produce a large change in the computed modulation. Thus the increase in antenna current cannot be used as a measure of modulation even under test conditions using pure tone modulation.

6–13. High-level and Low-level Modulation—A high-level modulation system is one in which the final stage of the transmitter is modulated, that is, the amplifier stage feeding the antenna. In low-level modulation, the modulation is accomplished at some earlier stage of the r-f amplifier system, hence the final r-f stage or stages operate as Class B linear amplifiers. In high-power radiotelephone transmitters, the low-level system is the less expensive, especially when the Class B linear amplifiers are operated in one of the improved efficiency circuits.

6–14. Class B R-f Amplifiers—The Class B linear r-f amplifier as used after a modulated stage requires critical adjustments of loading, bias, and excitation. The necessity for having good regulation of the r-f driver has been stressed in the previous chapter. If the linear amplifier is operated with bias beyond cutoff, it is possible to have complete modulation of the positive peaks even though the Class C amplifier stage is modulated only 60 to 70 percent. This was intentionally done in several early broadcast transmitters for the purpose of "picking up modulation." When done accidentally after a fully modulated Class C stage, it produces an overmodulated output.

A positive carrier shift[3] in a linear amplifier usually indicates excessive negative bias or too low an output impedance, or both. A negative shift is indicative of too low a bias, excessive r-f excitation, or load impedance too high, or a combination of all three.

6–15. Interference—Some of the conditions which usually result in causing interference to other stations will be reviewed here.

1. *Overmodulation.* Whenever a transmitter is modulated in excess of 100 percent (or if the modulation capability of the transmitter is exceeded before reaching 100 percent), interference beyond the normal bandwidth required for transmission results. "Modulation capability" is the limit of symmetrical modulation.

2. *Parasitic Frequencies.* Certain types of high-voltage tubes utilize the effects of secondary grid emission to aid excitation during the positive swing. A form of regeneration, at times it may result in the generation of self-oscillations having a frequency determined by the grid current. Other causes may likewise produce parasitic frequencies.

3. *Improper Neutralization.* Failure to neutralize all r-f amplifiers properly will cause the generation of spurious side bands during peaks of modulation.

4. *Phase Modulation.* There are several conditions which may cause phase modulation, such as poor regulation of the driving stage, the presence of a regenerative or degenerative power in the grid circuit (picked up from the tank or antenna circuit), or failure to tune the tank circuit to exact resonance.

5. *Frequency Modulation.* Frequency modulation is also a common cause of excessive band width in an amplitude-modulated transmitter. It may be caused by the oscillator being amplitude-modulated by reaction from the modulated amplifier. This condition, if present, can be identified by failure to secure a steady zero beat during modulation when the carrier is tuned in on a receiver and heterodyned by a stable oscillator.

6–16. Miscellaneous Modulation Difficulties—When distorted modulation cannot be remedied by adjustments of excitation, loading, or bias, it is well to look for a defective tube, particularly the modulator, modulator driver, or the tube being modulated.

If the modulation monitor shows excessive negative peaks and carrier shift downward with normal r-f excitation, it is a sign of low filament emission of the tube being modulated. Before subjecting the tube to an emission test or substituting another tube, the filament voltage should be checked ***at the socket*** terminals.

If the carrier shift is downward and the modulation peaks are equal, the power supply should be checked for regulation. Usually this condition is observed when a Class B modulator and the modulated amplifier have a common power supply.

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[2] If the positive and negative peaks are equal, it does not prove that there is no distortion since it is possible that both peaks could be distorted equally.

[3] See Section 6–24 for discussion of "carrier shift."

Class B modulators are very likely to produce distortion because of the necessity of a close balance between the two tubes. Since it is rare for both tubes to develop trouble at the same time, tube trouble can usually be noticed by an unequal swing on the two plate current meters. (This is not possible if only one meter, reading the total current, is provided.) Unequal swings may be due to other causes. For this reason, the two tubes should be switched in the sockets. If the low swing changes to the other meter when the tubes are shifted, the trouble is most likely a defective tube. The tube showing the lower plate current swing should be replaced. If practical, it is better to replace both tubes with a pair that have been especially selected for good balance. If the same meter continues to show a low swing when the tubes are interchanged, the trouble lies not in the Class B tubes but in the modulated amplifier (the r-f portion of the transmitter). (The assumption is that the driver and all the preceding audio amplifier stages are operating properly; for this reason it is recommended that the checking begin in the audio amplifiers.) Likewise, if the Class B plate current swings are equal for both tubes, it is probable that the distortion is in the r-f section of the transmitter.

A frequent cause of distortion that is difficult to isolate is a weak plate supply rectifier tube. However, if the plate voltages or plate currents are checked, the trouble can be spotted. The remedy is obviously to replace the rectifier tube.

If one of the audio amplifier stages is in trouble, the most likely cause is a defective tube. This can be conveniently tested by substituting a new tube. If the trouble persists, it is necessary to check the operating voltages. Apart from defective connections, resistors often may change in value or may open. Likewise, by-pass condensers may break down and thus short-circuit plate or grid-bias voltage. Do not neglect to measure the filament voltage since an improper voltage may cause low filament emission and thus introduce distortion. Occasionally some fault will short-circuit a portion of a de-coupling circuit. This short circuit will not change the voltages on the tube and therefore is often difficult to locate. Such trouble can be cleared only by carefully checking each circuit item.

If Class B modulators are used, trouble in this stage may be indicated by an abnormal action of the plate current—either by dipping instead of increasing or by an irregular shift, easily distinguished from the small upward pulses that follow heavy modulation when operating normally. A large upward shift indicates trouble in the Class B stage rather than trouble in the driver.

Most radiotelephone transmitters have several stages of audio amplification, as well as the modulators, included in them. As no jacks are provided for headphone monitoring (the level is much too high to permit it), the performance of each stage cannot be checked by a listening test. As a general rule, all stages preceding the modulator are operated in Class A. Fortunately, Class A amplifiers indicate distortion by a change in their plate current. Accordingly, a plate current reading should be taken of each audio amplifier stage in order, starting at the input. The proper order is necessary because the distortion introduced by the defective stage passes an unsymmetrical signal to the next stage and may cause a varying plate current in that stage even though it is working properly.

6–17. Single Side-band Suppressed-Carrier Radio Communication—Single side-band suppressed-carrier radio communication is used extensively in transoceanic radiotelephony and provides an equivalent improvement in radiated power of approximately 8 db over the conventional double side-band system.

In one system of single side-band suppressed-carrier radiotelephone operation, the carrier frequency is completely suppressed at the transmitter and subsequently restored at the receiver by means of a suitable local oscillator. In another system, the carrier is only partially suppressed. In the latter the partially suppressed carrier may be separated from the side band at the receiver by means of a suitable filter, whereupon it is amplified independently to the required strength. The carrier is then said to be *reconditioned.*

The reconditioned carrier may be recombined with the side band just prior to demodulation; or the reconditioned carrier may be employed to synchronize the frequency of a local oscillator which is combined with the side band. The reconditioned carrier may be employed, in either case, for automatic volume control purposes.

In single side-band systems, it is usually necessary to employ quartz crystal filters at the transmitters to obtain the necessary attenuation of the carrier and one side band, while passing, with little attenuation, the side band it is desired to radiate.

An economical method of fully utilizing a communication channel, often used in transoceanic radiotelephony, is to modulate each side band of the carrier with individual conversations. In this way, two different transmissions may be accommodated simultaneously while employing a single carrier frequency.

In the following section the word "modulation" is used in a manner which is common among scientists. While this usage differs from that of the prior pages of this chapter there is no basic difference in the idea. In this book we have used "modulation" to mean only the process by which a smooth stream of r-f power is caused to vary in accordance with music, voice or other "intelligence" which is to be transmitted to a distant receiver where it will

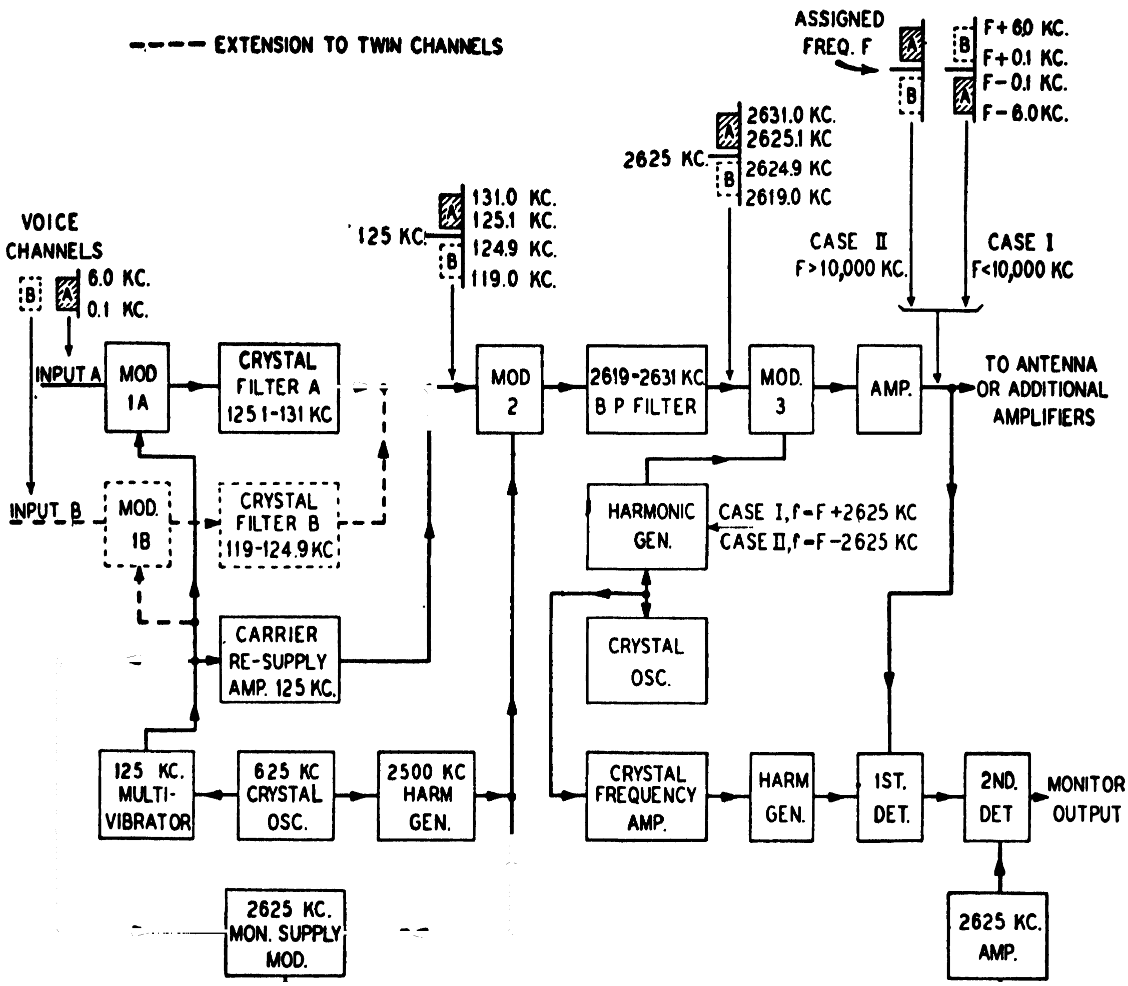

FIG. 6–17. Block schematic of single side-band transmitter. (Courtesy I.R.E.)

be reproduced. The process is always to feed two inputs (for instance r.f. and music) into a modulating device whose output is then found to contain the frequencies which were fed in, plus new frequencies which are mathematically predictable. In the simple amplitude-modulation example of section 6–5 we had:

First input	600 kc
Second input	5 kc

and the output was found to contain 600 kc, 5 kc and also 605 kc (sum of inputs) and 595 kc (the difference of the inputs). As is usually the case, not all of these frequencies were wanted, hence tuned circuits were used to select the wanted ones.

Another kind of "modulation" differing but slightly from the above is encountered when both inputs are at radio frequency. A familiar case is that of the common superheterodyne receiver. Here we may have, for example:

First input (from antenna)	1000 kc
Second input (from oscillator in receiver)	1465 kc

In this case the "modulator" is called a "converter" or "mixer" or "translator" and formerly it was also called "first detector." The output, as expected, contains these frequencies: 1000, 1465, 2465 and 465. Only the last is wanted; therefore it is selected by a tuned "i-f amplifier." This is the type of "modulation" referred to hereafter.

6–18. A Short-wave Single Side-band Radiotelephone System—In the following paragraphs is given a summary of a transmitting and receiving system employed by the American Telephone and Telegraph Company in transoceanic telephone service.[4]

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[4] A. A. Oswald. "A Short-Wave Single Side-band Radio Telephone System." *Proc. IRE,* Vol. 26, December 1938.

"*Transmitter System.* The arrangement of the single side-band radiotelephone transmitter used in this system is shown in Figure 6–17. The arrangement shown is complete for twin-channel operation. Channel A is the upper side band from the first step of modulation. Channel B is the lower side band. Three steps of modulation are employed to reach the final frequency, which may be any frequency between 4000 kilocycles and approximately 22,000 kilocycles. The conversion frequency (which in this case is the carrier frequency) for the first modulation step is 125 kilocycles. This frequency is derived from a multivibrator held in subharmonic relation by a 625 kilocycle quartz crystal oscillator. The first modulators are in duplicate, one for each channel. They are balanced modulators and a high degree of balance is maintained to suppress the conversion frequency in the output. Filters employing quartz crystals for some of the elements follow each first modulator. The filter in Channel A selects the upper side band lying between 125.1 and 131 kilocycles. The filter in channel B selects the lower side band lying between 119 and 124.9 kilocycles. When only a single channel is wanted the B modulator and filter are omitted.

"The amplitude of the radiated carrier is controlled by adjustment of the gain of the carrier-resupply amplifier which receives its input from the 125 kilocycle source. The signal outputs of the channel filters and the 125 kilocycle carrier are combined and applied to the second modulator. This is also a balanced modulator and a conversion frequency of 2500 kilocycles is employed. A harmonic generator driven by the 625 kilocycle oscillator supplies this frequency. The filter following this modulator selects the resultant upper side band, passing the band from 2619 to 2631 kilocycles. The suppression of the lower side band is at least 60 decibels.

"The third modulator is not balanced. The frequency of the wanted side-band output from this modulator is sufficiently far removed from the conversion frequency so that the selectivity of ordinary amplifier circuits is sufficient to suppress the conversion frequency and the unwanted side-band products without a special filter. This is an important feature because the circuits between the input of the transmitter and the third modulator remain fixed and are independent of the final radiated frequencies whereas the output circuits of the third modulator and all subsequent circuits require tuning when the radiated frequency is changed. The conversion frequency supplied to the third modulator depends on the final frequency desired. For a radiated carrier frequency *f*, which is 10,000 kilocycles or above, the conversion frequency is *f* minus 2625 kc. If *f* is less than 10,000 kilocycles the conversion frequency is *f* plus 2625 kilocycles. This conversion frequency is supplied by a harmonic generator driven by a quartz-crystal oscillator. Low-temperature-coefficient crystals are used without temperature control.

"Following the third step of modulation a series of amplifiers in cascade raise the level of the signal to the power required. In this transmitting system the final side-band frequency is derived at low power. The vacuum tubes employed in the system up to and including the first final-frequency amplifier are all conventional receiver type tubes.

"A monitor is provided in the transmitter by means of which distortion products in the transmitter output can be measured. A small amount of the transmitter output is combined in a demodulator with the third transmitter conversion frequency so as to produce a side band between 2625 and 2631 kilocycles in the case of channel A and between 2619 and 2625 kilocycles in the case of channel B. The 2500 and 125 kilocycle conversion frequencies are combined in a separate modulator and the sum is used in a balanced second demodulator to demodulate[5] the 2625 kilocycle side band to reproduce the input frequencies. There are no channel filters provided in the monitor and consequently there is no means of separating the channels should they both be active.

"*Receiving System.* The block arrangement of the receiver is shown in Figure 6–18. This diagram shows the equipment for twin-channel reception. For single channel operation the B-channel equipment is omitted.

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[5] "Demodulation" as used in this section means "detection."

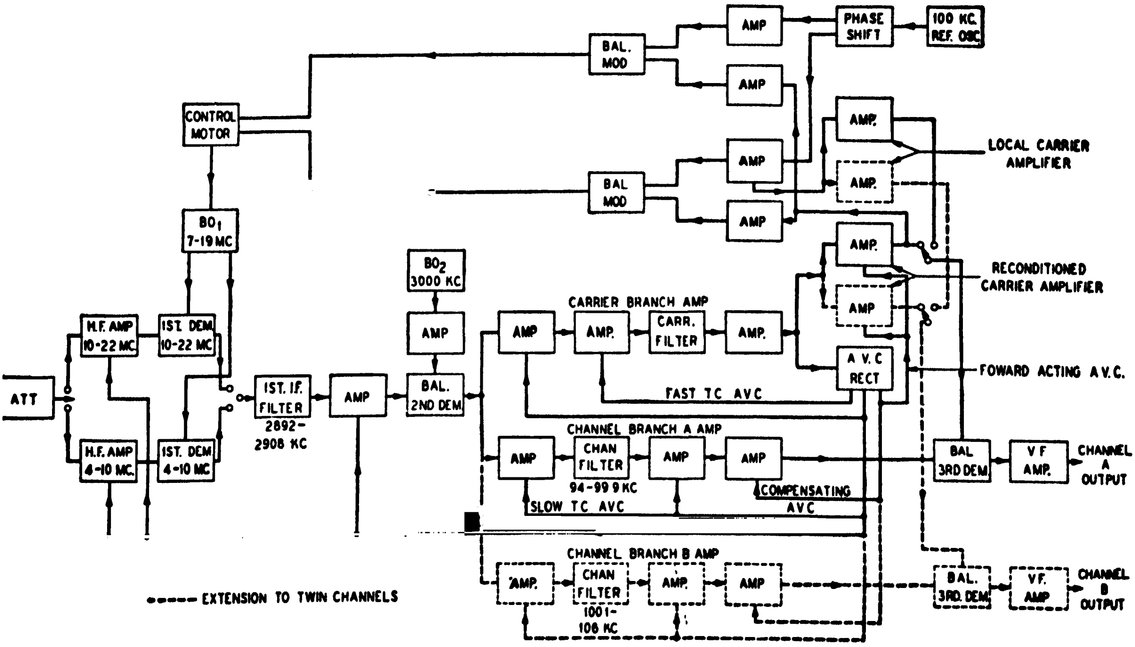

FIG. 6–18. Block schematic of single side-band receiver. (Courtesy I.R.E.)

"The receiver is designed to operate at any frequency in the range from 4000 to 22,000 kilocycles. This range is covered by two separate high frequency amplifiers and first demodulators. In order to attain a high degree of circuit stability, two separate sets of high frequency equipment are used rather than the more conventional method of changing coils. The received-carrier frequency is translated to 2900 kilocycles in the first demodulators. Following the first demodulator are filters which discriminate against frequencies which would cause interference in the 100 kilocycle second intermediate-frequency circuits. The relatively low frequency of 100 kilocycles is used for the second intermediate frequency in order to obtain the sharp cutoff characteristics required of carrier and channel filters. A 3000 kilocycle quartz crystal beating oscillator is used at the second demodulator to translate the 2900 kilocycle carrier to the 100 kilocycle.

"Following the second demodulator the circuit is branched to (1) a carrier-reconditioning and automatic-gain-control circuit, (2) the channel-A amplifier and filter circuits, and (3) the channel-B circuits, when required. The carrier-amplifier circuit supplies reconditioned carrier at constant volume for demodulating the signal at the third demodulators. It also supplies voltages to the gain control rectifier and to the automatic frequency control circuits. Quartz crystals are employed in the carrier filter and for some of the elements of the channel filters. These filters furnish high attenuation to frequencies outside of their respective pass bands, and have extremely sharp cutoff characteristics. The bandwidths are 40 cycles for the carrier filter and 5900 cycles for the channel filters.

"In order to maintain the signal in the proper relation to the crystal filters, a system of automatic frequency control of the first beating oscillator is employed. The frequency of the first beating oscillator is adjusted by a control motor in such a manner that the frequency of the reconditioned carrier is maintained in synchronous relation with that of a high precision 100 kilocycle quartz reference oscillator. This reference oscillator may also be used to furnish a local carrier for the final demodulation as an alternative to the normal reconditioned carrier.

"*Relation Between Channels and Side Bands.* In any single side-band transmitter where all equipment preceding the last stage of modulation remains fixed regardless of the radiated frequency, the side band and carrier at the input to the final modulator will always appear in the same frequency position. If the conversion frequency for the final step of modulation is placed above the desired radiated frequency the relative position of side band and carrier will be inverted, but if the conversion frequency is placed below the desired radiated frequency the position will not be changed. In a receiver wherein the second and third demodulators operate at fixed frequencies a similar situation arises if the position of the first beating oscillator frequency is changed from a higher frequency to a lower frequency than the received signal.

"For radiated frequencies less than twice the intermediate frequency, harmonics of the first beating oscillator are apt to be troublesome if the beating oscillator is below the radiated frequency rather than above it. The same is true in the transmitter. Therefore, it is desirable when working at frequencies less than twice the highest intermediate frequency to use a conversion frequency higher than the radiated frequency.

"On the other hand at the higher radiated frequencies it is desirable to use a final conversion frequency less than the radiated frequency. This yields higher frequency stability and a decreased range of oscillator tuning. Interchanging the relative frequency position of the conversion and radiated frequencies at some point in the frequency range reduces the total frequency range which must be covered by the conversion-frequency supply by twice the intermediate frequency. The same remarks apply to the receiver. For example, for a range of radiated frequencies from 4000 to 22,000 kilocycles with a first intermediate frequency of 3000 kilocycles the beating oscillator range need only be from 7000 to 19,000 kilocycles instead of 7000 to 25,000 kilocycles. As mentioned previously, this change in relative position of the conversion frequency results in an inversion of the radiated carrier and side band position. This presents no difficulty if the change is made at the same frequency at the transmitter and receiver. This procedure, of course, requires that an agreement be reached between the connecting agencies in regard to the radiated frequency at which the change in the relative position of final carrier and side band is to be made. In the apparatus described, this change can be made anywhere within the range from 10,000 to 15,000 kilocycles but 10,000 is preferred.

"In single-channel operation with the present transmitters and receivers, it is planned that for all radiated frequencies less than 10,000 kilocycles the carrier will be placed above the side band. In a twin-channel system the above applies to the A channel and the B channel will occupy the opposite position."

6–19. Speech Inversion—By beating the audio frequencies of the voice channel with a voltage derived from an a-f generator, a new order of frequencies is derived which, when used for modulating the carrier, provides a degree of secrecy for the user. When tuned in on a standard receiver, the voice sounds garbled and the transmission is sometimes referred to as scrambled speech. Some systems of scrambling are more complex than others and, unless the proper terminal equipment is employed, the conversations are unintelligible.

6–20. Relation of Modulation Frequency to Percentage of Modulation—Some interesting studies have been made in the field of high-fidelity broadcasting and its relation to the present allocation standards for broadcasting channels wherein the channels are separated by 10 kc. It has been determined from these studies that the maximum energy from a 75-piece orchestra falls in the frequency band from 125 to 250 cycles per second and that at 8000 cycles the signal may be as much as 30 to 45 db lower in intensity. Consequently, if the transmitter is modulated 100 percent by the higher level frequency components (the lower frequencies), the intensity at 8000 cycles would account for only slightly more than one-half of one percent modulation. Since the energy in the high-frequency audio spectrum is so low, it is essential to have standards of engineering practice that require the maximum reduction in carrier hum and extraneous noises, otherwise the high frequencies will be lost in the noise. In addition, the amplitude distortion in the transmitter must be reduced materially, otherwise the amplitude of the harmonics generated thereby would be greater than the fundamental frequency of some of the musical instruments being reproduced.

6–21. External Cross-modulation Interference—Although not directly related to the analysis of amplitude modulation, it is pertinent to mention an interference condition that develops at certain receiving locations as a result of the rectification of radio frequencies in power wiring and, in some cases, plumbing pipes making contact with other metals.

When two strong signals exist, a number of cross-modulation combinations take place. If the frequency of one station is designated *a*, and the other *b*, then the rectifier generates the following frequencies:

$a + b$
$a - b$
$2a$
$2b$
$2a + b$
$2a - b$
$2b + a$
$2b - a$
$3a$
$3b$ etc.

An effect also takes place whereby the modulation of station *a* is heard on station *b*, and the modulation of station *b* is heard on *a*.

It is important to note that these spurious frequencies do not depend upon the presence of harmonic radiation from either station. If both stations are entirely free of harmonic radiation, the same frequencies are generated if rectification takes place. It is essential to differentiate between cross modulation occurring in the receiver and that caused by rectification occurring externally. Generally, cross modulation within the receiver can be eliminated by means of a wave trap, tuned to the interfering frequency in the antenna lead or, in some cases, by shortening the antenna.

External cross modulation, if generated in the antenna-ground system, can be eliminated or attenuated by making certain that all antenna and ground connections are clean and secure. If rectification is occurring in the power wiring, it is helpful to connect two 0.1 μf condensers across the lines with the center point grounded. In any case, a good ground connection is essential.

Relocation of the receiver, as well as the use of a carefully placed receiving antenna connected to the receiver by means of a suitable transmission line, may be required before the trouble is finally eliminated.

6–22. Cathode-ray Oscillograph Modulation Measurements—The cathode-ray oscillograph is especially valuable in modulation measurements because the modulation can be seen continuously on the screen. It is not very satisfactory as a *measuring* device because the pattern is quite small, even with the comparatively large tubes. It is likely that an accuracy of 10 percent is about the best that can be obtained with a 5-inch tube; with smaller tubes, it is even less. The oscillograph should be considered a supplement to the more accurate modulation monitors; the cathode-ray tube, on the other hand, affords advantages in trouble shooting and for the making of photographic records.

Cathode-ray tubes can be utilized in several ways, differing in the source of the sweep voltage. These methods will be discussed separately in order to show their advantages and disadvantages.

1. *Modulated R.f. on Vertical Plates; 60-Cycle A.c. on Horizontal Plates.* The use of commercial 60-cycle a.c. from power lines to supply the sweep voltage has the advantage of simplicity as it requires no additional apparatus. It has several serious disadvantages. For one thing, unless the modulation frequency *happens* to be 60 cycles or an exact multiple of 60 cycles, the whole pattern will appear to be in rapid motion. This is true of all music where the frequencies of properly tuned instruments bear a relation to 256 cycles. This lacks 16 cycles of being an exact multiple, thus producing rapid motion. For another thing, the 60-cycle sweep traces back and forth across the screen 120 times per second. Vision persists for about $\frac{1}{15}$ of a second, so that at least 8 separate traces can be seen at once. Unless the screen is very "fast," it too will retain the image for a fraction of a second, increasing still more the number of images that will be seen at the same time. The result is a jumble of images, constantly changing, that is difficult to watch and practically impossible to measure.

A third disadvantage which holds for all cases where the modulated radio-frequency voltage is applied directly to either set of plates is that the beam covers an *area* on the screen. This involves two faults: the negative peaks are covered over by the positive peaks that may occur on the following traces, and the whole figure is not very well focused. The lack of focus is due to the heavy beam current that is necessary to produce a brilliant image over the large area. When the figure is only a *line*, the beam current is much more concentrated and gives a much brighter image even with lower beam current. At the lower current the focusing action is much more perfect.

The only really definite measurements that can be made on the negative peaks is the point where bright flashes appear along the center line. They indicate 100 percent negative peaks. At such instants the r.f. is momentarily cutoff and the pattern becomes a line. The line is much more brilliant than when the beam is spread over an area, thus making the flashes stand out very definitely.

2. *Modulated R.f. on Vertical Plates; Saw-tooth Sweep on Horizontal Plates.* Replacing the 60-cycle sweep voltage by a saw-tooth wave is a decided improvement. During single-frequency modulation, the sweep frequency can be adjusted to equal the modulation frequency or an exact integral fraction thereof. This makes the pattern stationary, and to a certain extent the succeeding traces coincide. During program transmission, the sweep frequency is adjusted to 256 cycles or an integral fraction thereof. Instead of a jumble of moving

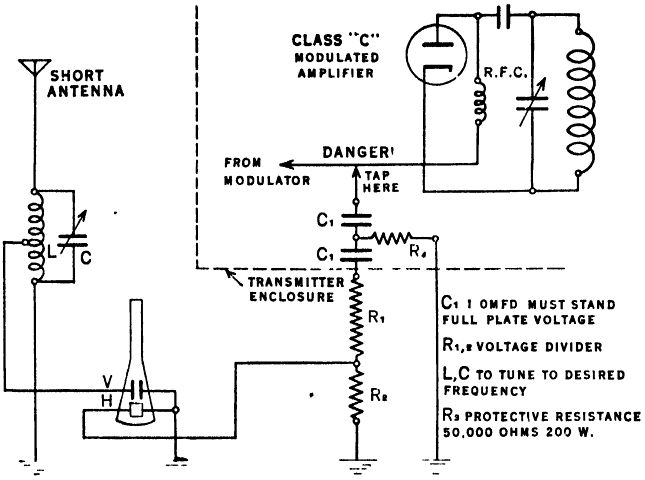
SHORT ANTENNA
CLASS "C" MODULATED AMPLIFIER
R.F.C.
DANGER!
FROM MODULATOR
TAP HERE
C1
C1
R4
TRANSMITTER ENCLOSURE
R1
R2
L
C
V
H
C1 1 OMFD MUST STAND FULL PLATE VOLTAGE
R1,2 VOLTAGE DIVIDER
L,C TO TUNE TO DESIRED FREQUENCY
R3 PROTECTIVE RESISTANCE 50,000 OHMS 200 W.

Fig. 6–19. Circuit for obtaining trapezoid pattern. Precaution must be exercised when using this circuit because of the high voltages involved.

figures we thus can usually obtain a single pattern. The pattern changes with the inflections of the voice or music, but this is much less violent than the rapid motion resulting from improper sweep frequency. The sweep frequency may be synchronized by hand, or the sweep oscillator may be controlled by the modulation so as to secure precise synchronism automatically. In this latter scheme, the sweep frequency is adjusted roughly by hand and then fed a small modulation frequency voltage through the proper terminal of the oscillograph. When an exact ratio is approached, the oscillator will pull into step.

For measuring the percentage of modulation, a low sweep frequency is desirable—perhaps 32 cycles. For examining the wave shape of the modulation, a higher frequency may be desirable. In either case, the precise adjustment can be maintained automatically.

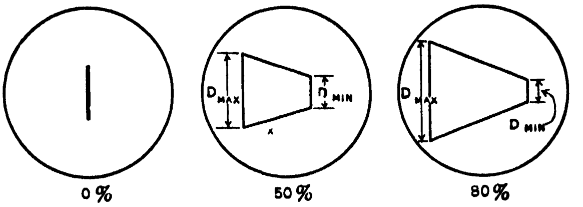

Fig. 6–20. Trapezoid patterns for different modulation percentages.

3. *Modulated R.f. on Vertical Plates; Modulating Voltage on Horizontal Plates.* If a portion of the modulating voltage is used for the sweep, the resulting figure is very simple—a trapezoid. The figure is stationary, but the shape changes with the percentage of modulation. Figure 6–19 shows how the oscillograph is connected, and Figure 6–20 shows the figure for several different percentages of modulation. This pattern is very easy to photograph or to measure. In addition to showing the percentage of modulation, this pattern is valuable because it shows overloading and overmodulation very clearly. In Figure 6-21a overloading is definitely indicated as the r.f. fails to increase with the modulation. The dotted lines show how the figure would appear if the overloading was corrected. This does not show the cause of the overloading, but the effect of remedies can be quickly and accurately checked. Figure 6–21b shows overmodulation. The modulating voltage is greater than is necessary to produce complete cutoff of the carrier on negative peaks. This appears as a bright line extending from the right-hand apex of the triangle.

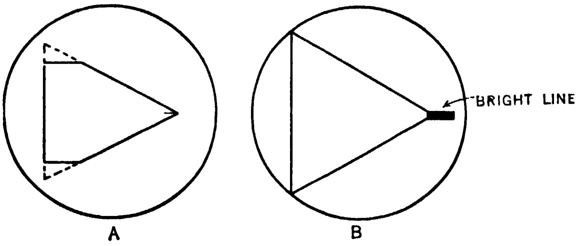

Fig. 6–21. In pattern A above the r.f. is failing to increase properly on positive modulation peaks indicating distortion. In pattern B over-modulation on negative peaks is indicated by the bright line at the apex of the triangle.

In applying this method, two precautions are necessary. First, since certain types of overloading and distortion can be plainly seen, operators sometimes assume that a perfect triangle pattern is a guarantee of no distortion. This is not true since distortion in any of the preceding audio stages will not be shown. The second precaution is with re-

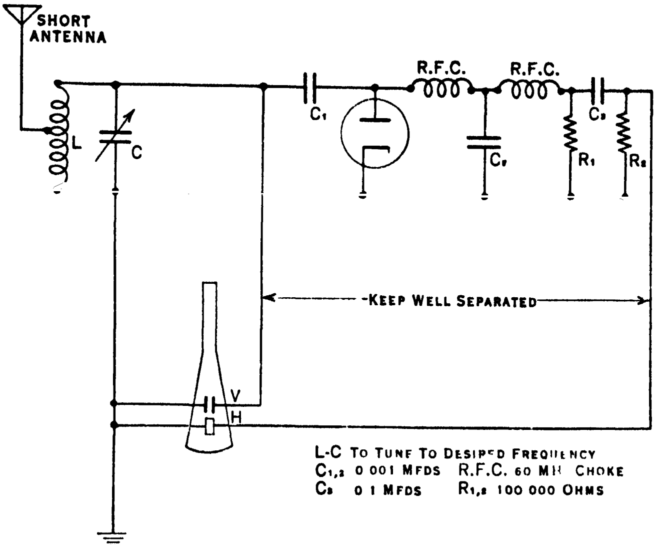

FIG. 6–22 A safer arrangement than Figure 6–19 for obtaining trapezoid patterns.

spect to the high voltages involved. A failure of any one of several parts would result in placing the entire modulator plate voltage on the oscillograph. It is, therefore, recommended that the case of the oscillograph be grounded very carefully and all wiring protected against contact by insulation capable of withstanding at least *twice* the modulator plate voltage. This *twice* is not a safety factor because the voltage at the modulator plate approaches twice the d-c value on modulation peaks.

A safer arrangement is shown in Figure 6-22. The carrier is picked up by the short antenna and is rectified to provide its own sweep voltage.

With the trapezoid figure, modulation is computed by measuring the height of the pattern on both sides. Denoting the greater height as $D_{\max}$ and the least height as $D_{\min}$, the modulation percentage is:

$$\text{Percentage modulation} = \frac{D_{\max} - D_{\min}}{D_{\max} + D_{\min}} \times 100$$

Because of the small size of the figure (it is limited by the area of the screen), the dimensions cannot be measured accurately. Consequently, the measurements cannot be depended upon any closer than about 10 percent.

6–23. Cathode-ray Oscillograms of Modulation—The cathode-ray patterns in Figure 6–23 to Figure 6–30 are shown by courtesy of John F. Rider as published in his book, *The Cathode-Ray Tube at Work*. They were obtained by equipping a transmitter with many controls so as to permit correct as well as incorrect adjustments and a variable percentage of modulation. The patterns shown are typical of the conditions stated, and tests conducted on other transmitters under similar conditions will result in patterns similar to these herein but not necessarily identical. Mr. Rider states that it has been his experience that the closest resemblance is obtained when the trapezoidal pattern is employed rather than the modulated wave envelope pattern.

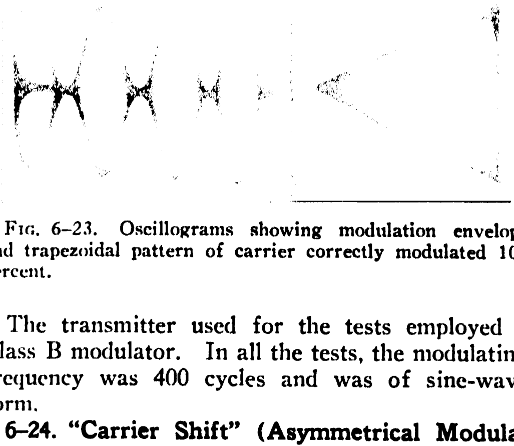

FIG. 6–23. Oscillograms showing modulation envelope and trapezoidal pattern of carrier correctly modulated 100 percent.

The transmitter used for the tests employed a Class B modulator. In all the tests, the modulating frequency was 400 cycles and was of sine-wave form.

6–24. "Carrier Shift" (Asymmetrical Modulation)—A Class C amplifier tube to be plate-modulated should behave in one regard like a pure resistance, that is, the plate current should vary in direct proportion to the plate voltage. This condition can be approximated (assuming there is no unneutralized feedback) by the application of proper load and bias, and especially by the use of adequate r-f grid excitation. The ratio of plate voltage to r-f output current then remains essentially constant during voltage variations (modulation) and there is little distortion during modulation. Failure to attain this condition will result in unequal ampli-

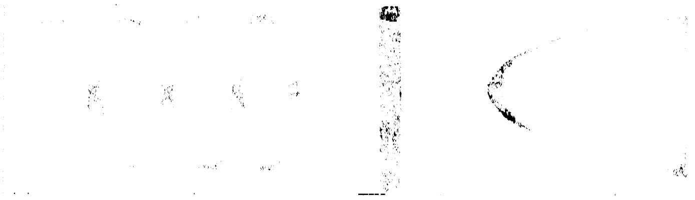

Fig. 6–24. Oscillograms of modulation with insufficient r-f excitation applied to modulated amplifier.

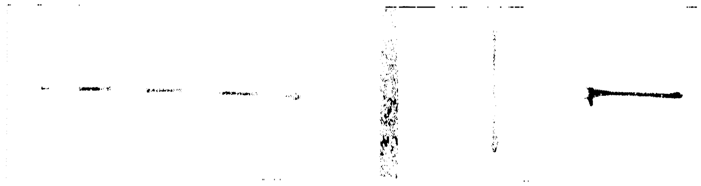

Fig. 6–25. Oscillograms showing effect of insufficient excitation and excessive bias voltage on modulated amplifier.

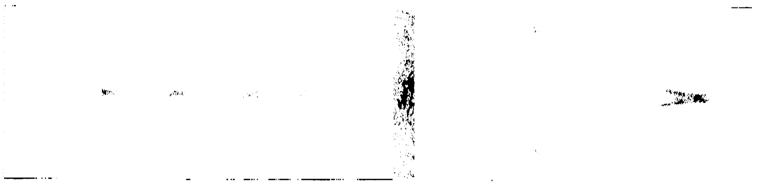

Fig. 6–26. Oscillograms showing nonlinear operation of modulated amplifier occasioned by incorrect grid bias.

tudes of the positive and negative modulation peaks, and this effect may be regarded as constituting a *shift in carrier amplitude*. Referring to Figure 6–31, the positive peaks of modulation are greater in amplitude than the negative peaks and consequently the carrier *power* has shifted upward. ***The expression "carrier shift" should not be interpreted to mean that the frequency of the carrier has changed during modulation.*** Such a frequency shift is termed dynamic instability of the carrier and has been previously discussed. Carrier shift upward occurs if the time average of the positive half cycles exceeds that of the negative half cycles; downward, or negative shift, occurs if the negative half cycles exceed the positive half cycles.

Fig. 6–27. Oscillograms showing severe distortion occasioned by imperfect neutralization of the modulated amplifier.

The half-wave linear diode rectifier shown in Figure 6–32 is the simplest device which permits monitoring a transmitter for evidence of overmodulation or carrier shift. In operation, the inductor *L* is coupled to the stage of the transmitter it is desired to monitor, and the coupling is adjusted so that sufficient radio frequency voltage is picked up to provide at least half-scale deflection on the milliammeter (0 — 1 ma) *M*. The filtering circuit, consisting of the r-f choke and two condensers C_1 and C_2, permits the rectified carrier to pass through the resistor *R* and milliammeter *M*. The resistor R improves the linearity of the rectifier. If the transmitter is free from carrier shift, the pointer of the meter will remain stationary during modulation. An upward movement of the pointer is indicative of positive or upward carrier shift; a downward deflection, of negative or downward carrier shift.

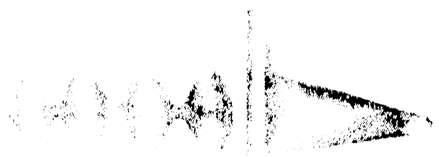

Fig. 6–28. Oscillograms showing distortion of same type as Figure 6–27. In this case oscillation is taking place during a considerable part of the modulation cycle and the effect on intelligibility of the received signal is ruinous.

A d-c milliammeter in the plate circuit of a plate-modulated transmitter, although not as sensitive or accurate as the linear rectifier, will also show an excessive movement either upward or downward if a transmitter is overmodulated with resultant carrier shift.

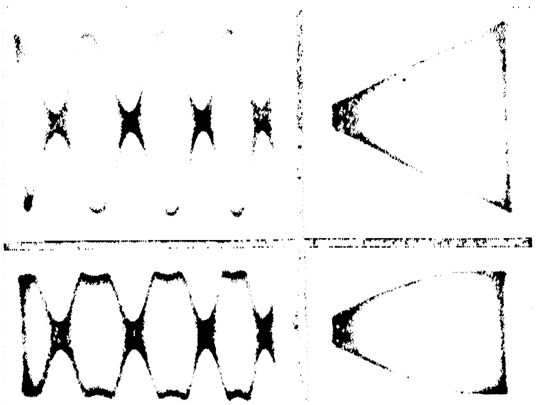

FIG. 6–29. Oscillograms showing the importance of proper tuning of the modulated amplifier tank circuit. The upper two photographs show the good results obtained with correct tuning while the lower two photographs show the severe distortion resulting by merely mistuning the tank circuit.

6–25. Negative-peak Overmodulation Indicator—The vacuum tube rectifier, as connected in Figure 6–33, operates as an indicator of negative-peak overmodulation. When overmodulation occurs, the negative peaks are flattened or cut off, resulting in a discontinuity of the carrier. When this occurs, the plate voltage on the modulated tube reverses, and the filament of the rectifier, although normally positive with respect to ground, becomes negative and rectified current passes through the meter *M*.

6–26. Vacuum-tube Peak Voltmeter—The vacuum-tube peak voltmeter has for many years been used to measure the percentage of modulation of radiotelephone transmitters. The circuit of Figure 6–34 shows the electrical connections for a vacuum-tube peak voltmeter, the operation of which is as follows:

The potentiometer R_1 is set at zero (movable arm set at negative connection to R_1 and sufficient negative bias is applied to the grid of the tube by adjustment of potentiometer R_2 until the plate current is just at zero. Sufficient unmodulated carrier current is obtained from the transmitter by adjustment of coupling and variations in condenser *C* until the milliammeter reads a convenient deflection, at least half scale. The potentiometer R_1 is then adjusted until the milliammeter deflection is just at zero. The voltmeter reading *E* is then equal to the peak radio frequency voltage of the carrier and is proportional to the carrier current I_{car}.

The coupling is left undisturbed and sustained sinusoidal modulation is applied. R_1 is then further adjusted until the plate milliammeter again reads zero. The voltage *E*, as read from the voltmeter is the peak value of the modulated r-f voltage and is proportional to I_{mod}. The percentage of modulation may then be calculated by substituting the voltage readings in the formula, as they are proportional to the current values:

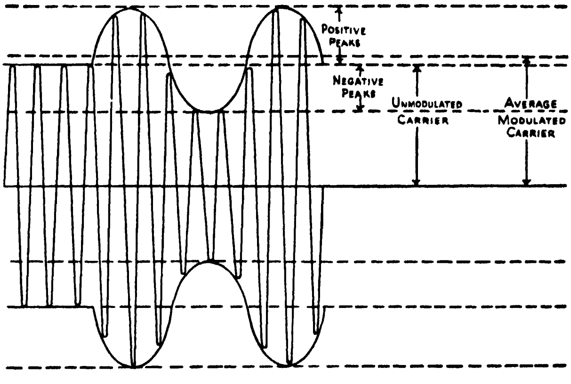

FIG. 6–31. Positive carrier shift.

$$M\% = \frac{I_{mod} - I_{car}}{I_{car}} \times 100$$

where I_{mod} = peak value of modulated carrier current

I_{car} = peak value of unmodulated carrier current

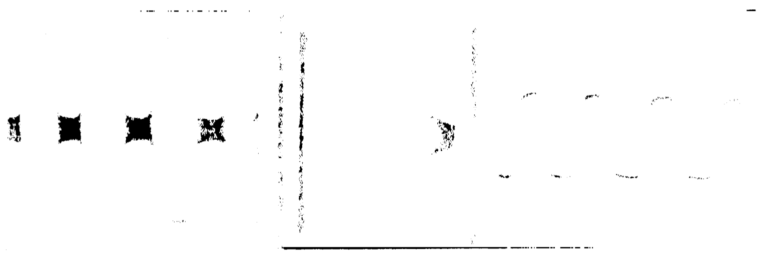

FIG. 6–30. Oscillograms showing effect of incorrect loading of the Class B modulator. The distorted audio wave form resulting from the incorrect load impedance measured across the secondary of the modulation transformer is shown at the right. Its effect can be seen in the r-f patterns.

This device permits a determination of the percentage of modulation but does not give any indication of the symmetry of the positive and negative peaks.

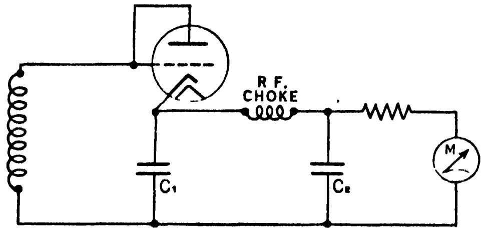

Fig. 6–32. A circuit employing a linear diode rectifier for monitoring a transmitter for evidence of overmodulation or carrier shift.

6–27. Modulation Measurement by Component Method—A simple means of measuring modulation is to separate the d-c and the a-c components of the modulated wave after it has been rectified and filtered. The d.c. is proportional to the carrier, and the a.c. is proportional to the modulation. By comparing the two values, the percentage of modulation can be found. This is shown by Figure 6–35. (A) shows the modulated r-f wave. After rectification (B) it becomes a pulsating d.c. The pulsations have both radio and a-f components.

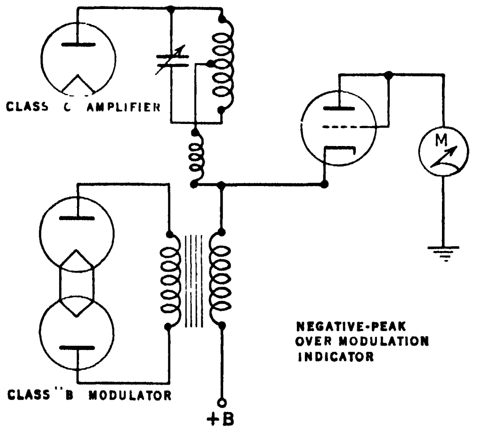

Fig. 6–33. Negative-peak overmodulation indicator.

The r-f components can be filtered out, and we then have the pulsating d.c. shown as (C). The a-c and d-c components of this pulsating d.c. can be separated by the arrangement of Figure 6–36. The d-c component will pass through branch 1, but not through branch 2. The a-c component can flow through the blocking condenser into branch 2, but will be kept out of branch 1 by the audio choke coil L_2.

The d-c component, which corresponds to the carrier, can be read very conveniently by a high resistance d-c voltmeter. With conventional tubes (small receiving triodes with grid and plate connected are quite satisfactory) it is suggested that the r-f pick-up be adjusted to produce about 50 to 100 volts of rectified carrier. The meter should have an internal resistance of about 100,000 ohms. (This corresponds to a 0–100 voltmeter with a resistance of 1000 ohms per volt.) It should be mentioned that mercury-vapor rectifier tubes are not suited to this circuit since their constant internal voltage drop interferes with the measurements.

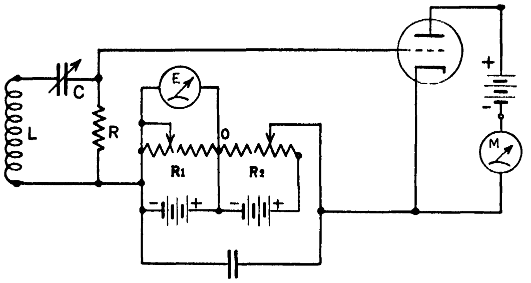

Fig. 6–34. Peak or slide-back type vacuum tube voltmeter.

The a-c component can be measured in any one of a number of different ways. The simplest is by means of a high resistance a-c voltmeter. The instrument must be accurate over the entire audio range and should have a sensitivity of 1000 ohms per volt. Although simple, this method is open to the serious objection that meters of the ordinary type measure the rms value and not the peak value.

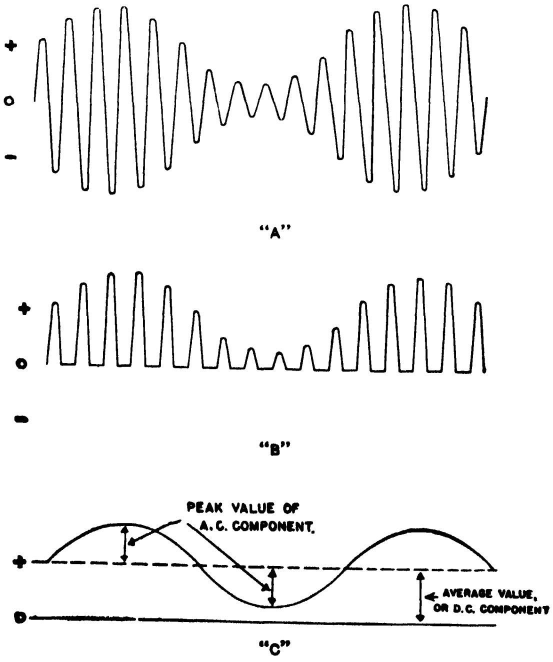

Fig. 6–35. Shown above are: (a) modulated r-f wave, (b) modulated r-f wave after rectification, (c) modulated r-f wave after rectification and filtering.

Accordingly, the readings will be useful only when the modulation is a sine wave. In addition, the reading is an average of positive and negative modulation and there is no means of measuring them separately.

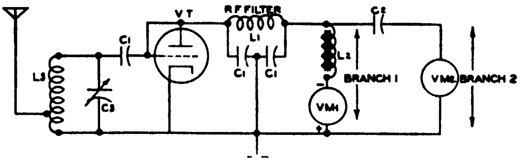

FIG. 6–36. Modulation meter using the component method.

Tune C_3 to resonance as indicated by maximum deflection of VM-1. Adjust length and position of antenna until VM-1 reads 70.7 volts. VM-2 will now read full scale (50 volts) at 100-percent modulation. Multiply VM-2 reading by 2 to obtain the percentage of modulation.

6–28. Modulation Measurement by the Double Rectifier Method—The simplest arrangement capable of measuring peak modulation is illustrated in Figure 6–37. The rectified and filtered modulated wave appears as a pulsating d.c. across terminals A and B. Terminal A is negative and terminal B positive with the rectifier connections as shown. In this pulsating d.c., the average value represents the carrier, the highest voltages reached are caused by the positive modulation peaks, and the lowest voltages result from the negative modulation peaks. In series with this rectified modulated wave (or pulsating d.c., as it now is) is a variable d-c voltage, supplied from battery B and adjustable by means of potentiometer P. The switch S in series with the potentiometer is merely to keep the potentiometer from discharging the battery when the device is not in use and has no function in making measurements. The battery polarity is opposite to that of the pulsating d.c. (the rectified modulated wave). The sum of these two voltages is connected to a reversing switch (points A and C on the figure).

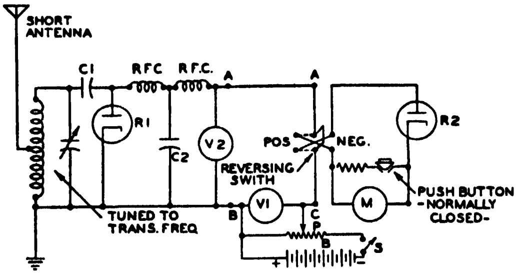

FIG. 6–37. Modulation meter.

When the reversing switch is in the position shown by the dotted lines, the current can flow through the meter M only when point C is positive with respect to point A. The rectifier R_2 prevents any current flow in the opposite direction. This will occur if the pulsating d.c. (the rectified modulated wave) becomes greater than the battery voltage at any portion of its cycle. By carefully adjusting the potentiometer until current just begins to flow through meter M, and reading voltmeter V_1, we can determine the highest value attained by the rectified modulated wave. This corresponds to the positive modulation peak.

If the reversing switch is thrown to the opposite position, the meter M will register only when point C is negative with respect to point A. The polarity of the rectified modulated wave is such as to oppose this condition. The least opposition is given at the moment of a negative modulation peak. The voltage at this instant can be measured by carefully adjusting the potentiometer to the point where current just begins to flow through the meter M, and then reading voltmeter V_1.

The carrier voltage may be read by an ordinary high-resistance d-c voltmeter connected across the terminals A–B. It is important that this meter be connected in the circuit when the measurements are made since removing it will allow an increase in the rectified carrier voltage. (The voltmeter V_1 cannot be used for both readings as it is necessary that both are connected at the same time.) If the carrier voltage is V_c, the positive modulation peak voltage V_p, and the negative peak voltage V_n, the percentages of modulation are expressed as:

$$\begin{aligned}\text{Positive modulation \%} &= 100(V_p - V_c)/V_c\\ \text{Negative modulation \%} &= 100(V_c - V_n)/V_c\\ \text{Percentage modulation}^{6} &= 100(V_p - V_n)/2V_c\end{aligned}$$

This type of modulation meter is subject to an inherent error. All positive measurements are slightly lower than the true value, and all negative measurements are slightly higher than the true value. This occurs because the equation assumes that the voltages (instantaneous rectified carrier voltage and potentiometer voltage) are equal. Actually one of them must be slightly greater in order to produce a detectable current through the meter M. The error depends upon the sensitivity of this meter, and the amount of rectified carrier voltage. To ensure an accuracy of 2 percent, the meter should have a full-scale sensitivity of 200 microamperes and the rectified carrier be at least 50 volts. Somewhat higher voltage is desirable provided the amount of power taken from the transmitter is not excessive. *The microammeter should be provided with a heavy shunt.*[7] *After an approximate setting has been found, the shunt can be removed by a push-button type switch and a precise adjustment found. Unless this precaution is taken, it is quite probable that the meter will be burned out before the first reading is taken.*

Although modulation meters of this type are very satisfactory for testing transmitters, they do not give a continuous indication of the modulation and, therefore, are not well suited for monitoring. For

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[6] The percentage modulation is defined by the FCC as the average of the positive and negative modulation percentages.

[7] A suitable shunt is one which would make the full scale reading about 5 ma.

example, if the potentiometer is set at a voltage corresponding to 75-percent modulation, the meter will "kick" each time the modulation exceeds this figure. This will occur only during loud program passages. The remainder of the time the instrument will give no indication as to the percentage of modulation unless readjusted continuously.

6–29. Direct-reading Double-rectifier Modulation Measurement—For monitoring, it is highly desirable that the modulation meter shall indicate the percentage of modulation directly on a meter. The double-rectifier type of modulation meter can be made to do this by the addition of a condenser, a resistor, and a more sensitive microammeter. Figure 6–38 shows the circuit arrangement. The potentiometer is fixed at a voltage just equal to the rectified carrier voltage. The voltage across the terminals *A–C* is alternating, the positive half cycles representing the positive modulation peaks, and the negative half cycles representing the negative peaks. The rectifier tube uses either series (depending upon the position of the reversing switch) of half cycles to charge the condenser *C*. This is the equivalent of a condenser input filter. It is characteristic of such a filter that the d-c voltage is nearly equal to the peak value of the impressed a.c. In this case the peak value of the impressed a.c. corresponds to the peak modulation. The resulting d-c voltage is measured by means of the sensitive meter in series with the resistor *R*. The condenser *C* can charge up quite rapidly, the only resistance to charging being the internal resistance of the two rectifier tubes and a portion of the potentiometer, in all probably not more than 5000 ohms. On the other hand, the condenser can discharge only through resistor *R*. With a capacitance of 0.25 μf and a resistance of 1,000,000 ohms, it will take roughly one-quarter of a second for the condenser to discharge. Before this much time can elapse, successive modulation peaks will have renewed the charge, so that the condenser voltage will always stay close to the peak value of the rectified voltage. This action is shown in Figure 6–39. The first peak charges the condenser almost to its peak value. The condenser is still fairly well charged when the second peak comes. This raises the condenser voltage almost to the peak value. The third peak is lower but does not affect the condenser because the condenser voltage has not fallen to that point. As this process goes on, it will be observed that the condenser voltage reflects the peaks very well. Also note that its variation is very small so that a meter would show a fairly steady reading, rising rapidly when a new peak is reached, and then falling back slowly. This is ideal for modulation monitoring.

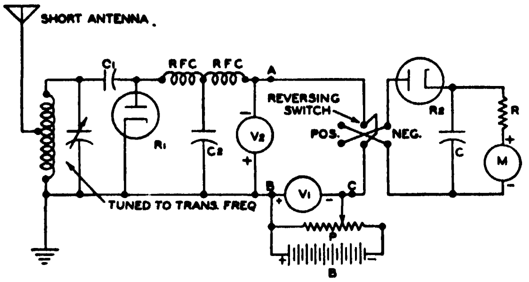

Fig. 6–38. Direct-reading modulation meter.

With the suggested resistor value of 1,000,000 ohms, and a carrier pick-up of 50 volts, the microammeter should read full scale (50 microamperes) for 100-percent modulation. The rectified carrier voltage may be read across *A–B* in the usual way with a sensitive 1000 ohms per volt d-c voltmeter.

6–30. Commercial Monitoring Devices—Commercial monitoring devices, some of which have been approved by the F.C.C. for use at broadcasting stations, are based, in general, on the same principles as the simple devices so far described. However, they have been refined to permit more rapid and convenient operation and also to make possible some additional measurements. Since such devices change from time to time, the operation should be based, in each case, on a careful reading of the manufacturer's instructions for the device. To attempt to carry the practices of one device over to one of a different make may result in serious error. The F.C.C. requirements regarding the use of modulation monitors at broadcast stations, as well as the requirements for approval of modulation monitors, are given below.

Rule 3.55. (*a*) A licensee of a broadcast station will not be authorized to operate a transmitter unless it is capable of delivering satisfactorily the authorized power with a modulation of at least 85 percent. When the transmitter is operated with 85 percent modulation, not over 10 percent combined audio frequency harmonics shall be generated by the transmitter.

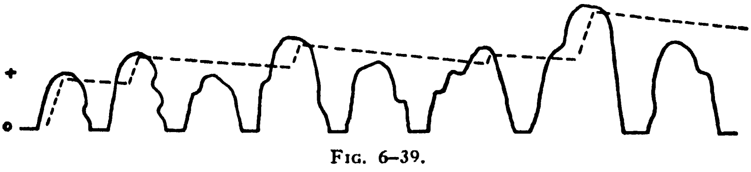

Fig. 6–39.

------------ Condenser voltage

———————— Rectifier output

With the circuit of 6–38 the condenser charges rapidly but discharges slowly thereby producing a damped meter action.

(*b*) All broadcast stations shall, on and after November 1, 1936, have in operation a modulation monitor approved by the Commission.

(*c*) The operating percentage of modulation of all stations shall be maintained as high as possible consistent with good quality of transmission and good broadcast practice and in no case less than 85 percent on peaks of frequent recurrence during any selection which normally is transmitted at the highest level of the program under consideration.

(*d*) The Commission will, from time to time, publish the specifications, requirements for approval, and a list of approved modulation monitors.

The specifications that the modulation meter shall meet before it will be approved by the Commission are as follows:

1. A d.c. meter for setting the average rectified carrier at a specific value and to indicate changes in carrier intensity during modulation.

2. A peak indicating light or similar device that can be set at any predetermined value from 50 to 120 percent modulation to indicate on positive peaks, and/or from 50 to 100 percent negative modulation.

3. A semi-peak indicator with a meter having the characteristics given below shall be used with a circuit such that peaks of modulation of duration between 40 and 90 milliseconds are indicated to 90 percent of full value and the discharge rate adjusted so that the pointer returns from full reading to 10 percent of zero within 500 to 800 milliseconds. A switch shall be provided so that this meter will read either positive or negative modulation and, if desired, in the center position it may read both in a full-wave circuit.

The characteristics of the indicating meter are as follows:

Speed—The time for one complete oscillation of the pointer shall be 290 to 350 milliseconds. The damping factor shall be between 16 and 200. The useful scale length shall be at least 2.3 inches. The meter shall be calibrated for modulation from 0 to 110 percent and in decibels below 100 percent with 100 percent being 0 db. The accuracy of the reading on percentage of modulation shall be ± 2 percent for 100 percent modulation, and ± 4 percent of full scale reading at any other percentage of modulation.

4. The frequency characteristics curve shall not depart from a straight line more than ± ½ db from 30 to 10,000 cycles. The amplitude distortion or generation of audio harmonics shall be kept to a minimum.

5. The modulation meter shall be equipped with appropriate terminals so that an external peak counter can be readily connected.

6. Modulation will be tested at 115 volts ± 5 percent and 60 cycles, and the above accuracies shall be applicable under these conditions.

7. All specifications not already covered above, and the general design, construction, and operation of these units must be in accordance with good engineering practice.

6-31. General Radio Type 1931-A Amplitude-Modulation Monitor—The modulation monitor is used to measure and to indicate continuously the percentage modulation of broadcast and other radiotelephone transmitters. The type 1931-A modulation monitor performs the following specific functions:

1. Measurement of percentage of modulation on either positive or negative peaks.
2. Overmodulation indication.
3. Program level monitoring.
4. Measurement of carrier shift when modulation is applied.
5. Measurement of transmitter audio-frequency response.

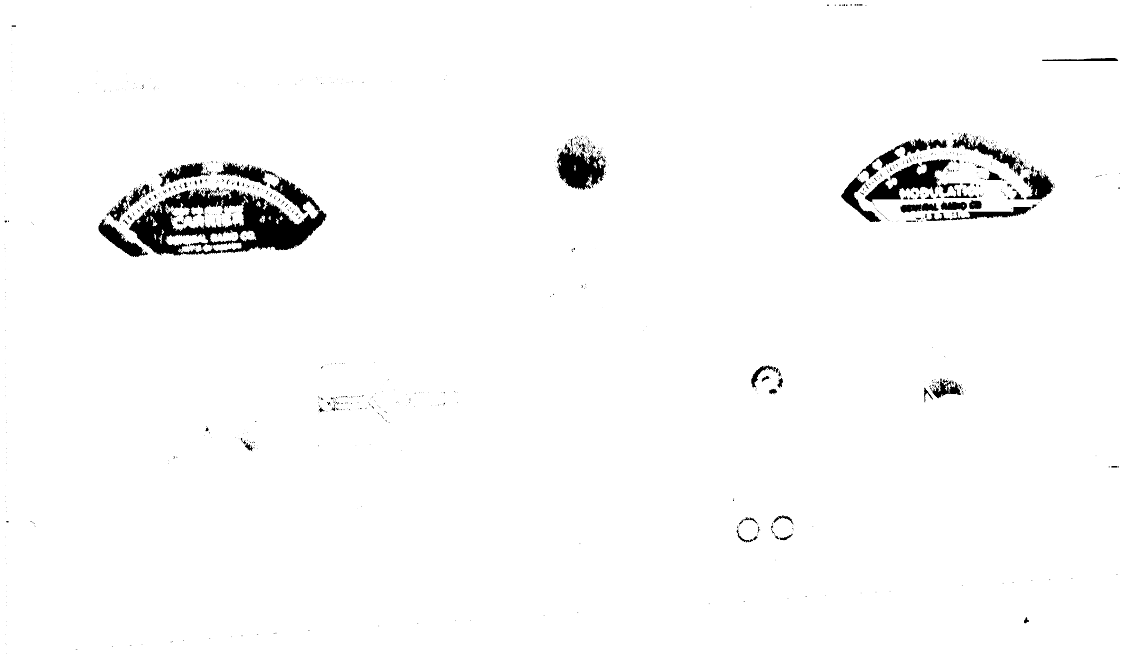

Fig. 6-40. The General Radio type 1931-A amplitude-modulation monitor.

The type 1931-A modulation monitor consists of three essential elements: (1) a linear diode rectifier that gives an instantaneous output voltage proportional to the carrier envelope; (2) a peak voltmeter that gives a continuous indication of the peak modulation; and (3) a trigger circuit that flashes a light whenever the modulation momentarily exceeds any previously set value.

The linear rectifier is designed for operation at a low power level, which greatly simplifies the coupling to the transmitter. In the output of the linear rectifier is a d-c meter that indicates the carrier level at which the instrument is operating and also shows any carrier shift during modulation.

In addition, two auxiliary audio output circuits operating from a separate diode rectifier are provided. One of these, at 600 ohms, is intended for audible monitoring; the other, a high-impedance circuit, gives a faithful reproduction of the carrier envelope with less than 0.1-percent distortion and can be used for distortion and noise-level measurements.

Speed and simplicity of operation, essential for monitoring instruments, are available in this instrument. It operates over a wide carrier-frequency range, and a tuned input circuit is provided to facilitate coupling to the transmitter.

The r-f power input is only a fraction of that required by older models. This greatly simplifies coupling to the transmitter.

The flashing lamp is extremely useful as a monitoring device. It is set to flash with moderate frequency when the transmitter is operating normally. If the flashing rate changes markedly, the operator is made aware that the average level of modulation has changed. The flashing circuits are so designed that the indication is unaffected by moderate changes in carrier amplitude.

Terminals are provided so that remote percentage modulation indicators can be connected to the instrument externally.

6-31a. Circuit Details—The input circuit to the monitor consists of a low-impedance coupling coil L_4 coupled to a tuned circuit consisting of L_8 and C_1. The resistors R_1 and R_2 load this circuit sufficiently to eliminate side-band cutting over the operating range of the monitor.

The voltage developed across the tuned circuit is applied to the double diode V1. One of the diodes feeds the monitoring circuit, the other provides an essentially distortionless reproduction of the r-f envelope for distortion measurements.

The modulation meter diode is followed by an r-f filter consisting mainly of choke L_5 which removes all the r-f components, leaving only a negative d-c component that is proportional to the average level and an a-c component that is proportional to the varying envelope of the original modulated carrier. Relative carrier level is indicated by a d-c meter in series with the diode rectifier.

For the indicating meter circuit, the a-c component is linearly amplified and applied to a peak response half-wave diode voltmeter. The diode can be reversed in polarity by means of a panel switch so that either positive or negative peaks can be measured. A highly stable degenerative d-c amplifier follows the diode and includes the d-c indicating meter. The meter has a high-speed response characteristic to meet F.C.C. specifications for this type of monitor.

For the warning-lamp circuit, the a-c component is applied directly to the grid of an amplifier tube. Any given percentage of the negative d-c component is chosen by the setting of a potentiometer, which is calibrated to 0–100 percent modulation. Whenever the a-c component exceeds the negative d-c component, the amplifier tube operates to trigger a thyratron tube. A warning lamp connected in the anode circuit flashes, indicating the presence of a modulation peak in excess of the dial setting.

The other section of the double diode V1 is used to supply a distortionless envelope output for distortion measurements with the type 1932-A distortion and noise meter. The diode is followed by an r-f filter and a voltage divider ganged with the MODULATION PEAKS control. This output is available at the multipoint connector at the rear of the instrument and is indicated on the elementary schematic as ENVELOPE OUTPUT.

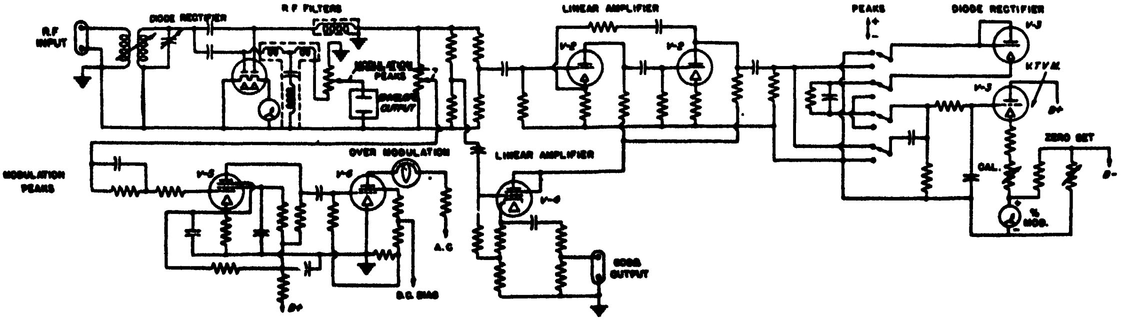

Fig. 6–41. Elementary schematic circuit diagram of General Radio 1931-A amplitude modulation monitor.

The use of separate diodes for modulation measurements and distortion measurements isolates the two instruments electrically and prevents any interaction between them that might otherwise affect the accuracy of measurement. A high-fidelity audio output operating from the same diode used for distortion measurements is also provided for a-f monitoring purposes. The output of this amplifier is independent of all panel controls and can be loaded without causing any reaction upon other circuits in the monitor. The internal impedance is approximately 600 ohms. This outut is available at the rear for permanent cable connections and also at panel jacks. Plugging into the panel jacks automatically disconnects the plug at the rear.

All indicating meters are of the Weston, model 891, illuminated type. Connections at the rear of the instrument provide for connecting a remote percentage modulation meter, if desired.

6–31b. Installation—1. *Input Coupling.* Two sets of input tuning coils are available to cover the carrier-frequency range. One set, consisting of the type 1931–P5–1 tuning coil and the type 1931–P5–2 coupling coil, covers the 0.5 to 8 mc portion of the range. The other set, consisting of the type 1931–P6–1 tuning coil and the type 1931–P6–2 coupling coil, covers the 3 to 60 mc portion of the range. The tuning coil of each set covers its portion of the range in four steps as selected by the setting of a connecting strap on the coil. The frequency range for each of the four steps is indicated by engraved numerals adjacent to a terminal on the tuning coil.

When the type 1931–P6–1 tuning coil is used, the connecting strap must connect the central terminal of the coil to the terminal for the desired frequency range.

When the type 1931–P5–1 tuning coil is used, the triangular connector provided with the coil must connect the central terminal to either one or two of the other terminals, depending on its position, and must be oriented so that the arrow on the connector points to the terminal for the desired frequency range.

The set of coils provided with the monitor can be easily removed and replaced with the set for the carrier-frequency range.

The coupling coil of a set is mounted with two screws on the mounting block of the carrier control shaft.

The tuning coil is mounted with two thumb nuts on the brackets either side of the shaft. A plug on the tuning coil must be inserted in a corresponding jack on the instrument.

Side-band clipping varies directly with tuning capacitance. While side-band clipping will in any event be less than 0.5 db for modulating frequencies below 15 kc, it is advantageous to use the lower tuning capacitance when there is a choice because of overlap in coil ranges.

2. *Coupling to Transmitter.* This instrument has been designed to operate from the standard R.M.A.[8] monitor-output connection, which will provide an ouput of 10 volts into a load of 75 ohms. For those transmitters not provided with a monitor-output connection, the most convenient way to couple the type 1931–A modulation monitor to the transmitter is to install a small coil of a very few turns close to the antenna lead or to the tank circuit. This coil is then connected to the monitor input terminals by a suitable line. An ordinary rubber-insulated single-conductor concentric cable of around 75 ohms impedance has been found convenient. This forms a low-impedance link circuit with the coil mounted in the monitor.

Sufficient coupling must be provided so that when the instrument is turned on, the carrier meter can be set to 100 after the signal has been tuned to resonance by means of the TUNE FOR MAXIMUM control. Some margin in the setting of the carrier SET TO 100 control knob must be allowed to compensate for changes in the transmitter output or in the coupling system. The TUNE FOR MAXIMUM control must be very carefully set to resonance.

The tuned circuit in the instrument is shunted by two 10,000 ohm resistors in parallel. If one of the resistors is removed, somewhat less power will be required to operate the instrument, but side-band clipping will be increased, although not to a serious extent. At the higher carrier frequencies, these load resistors may be removed without increasing side-band clipping appreciably.

3. *Power Supply.* The instrument can be operated from any 115/230 volt, 50–60 cycle line. Connections on the power transformer enable the input to be changed from 115 to 230 volts, if required. The power supply nameplate is reversible and should be turned over if the transformer connections are changed. Internal voltage regulators permit stable operation of the instrument over a range of 105–125 (110–250) volts.

The connector furnished with the instrument must be plugged into the rear Jones socket in order to obtain readings on the PERCENTAGE MODULATION METER. The electrical circuit is completed by a connection between terminals 7 and 10. If a remote meter is used, remove this connection and add the external meter circuit between terminals 7 and 8. (The external impedance thus added should be 600 ohms ± 20 percent.)

The 600-ohm audio monitoring output is available at terminals 11 and 12. Terminal 12 is grounded, and should connect to the external line shield. This circuit cannot be used with balanced lines, but must be operated with one side grounded.

Terminal 9 is the audio output to be used with the type 1932–A distortion and noise meter only.

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[8] Radio Manufacturer's Association.

6-31c. Operation—1. *Procedure.* Turn on the power switch. With the power on and no carrier applied, the carrier meter should read zero. The mechanical adjustment should be used, if necessary. With power on and no carrier applied, the percentage modulation meter should read zero. The mechanical adjustment on the meter may be used to bring it to zero. This check can be made when the carrier input is applied to the instrument if the carrier is unmodulated. If this is done, be sure the modulation due to noise is not sufficient to deflect the meter.

With the carrier applied but with no modulation, tune for maximum reading of the carrier meter. For this adjustment, the SET TO 100 carrier control should be set back sufficiently so that the meter reading does not exceed 100. After the instrument has been tuned for resonance, the SET TO 100 control may be advanced to obtain a reading of 100 on the meter. Retune if necessary. With the circuit correctly tuned to resonance and with the meter reading 100, all direct-reading scales are standardized. When modulation is applied, any shift in average carrier amplitude may be read directly in per cent on the carrier meter.

If the transmitter is now modulated, the PERCENTAGE MODULATION meter will read the instantaneous percentage modulation, and readings for either positive or negative peaks can be obtained by means of the PEAKS switch. The MODULATION PEAKS dial can be set at the maximum value of percentage modulation at which it is desired to operate, and the OVERMODULATION lamp will flash whenever this percentage is exceeded. The lamp operates on negative peaks.

2. *Distortion and Noise Measurements.* When the type 1932-A distortion and noise meter is used with the monitor, an interconnecting shielded cable is supplied. This is clearly marked with the instrument type numbers on either end, to identify the proper position. When the instruments are installed in a relay rack, with the 1931-A *above* the 1932-A, this cable will be found to fit easily in place.

It is important that the MODULATION PEAKS dial be set at approximately the modulation level indicated on the PERCENTAGE MODULATION meter when these measurements are made. If the dial is not set in this manner, distortion readings obtained on the type 1932-A distortion and noise meter may be slightly high.

If the dial is set too far below the actual percentage modulation, distortion at the higher audio frequencies will be introduced by excessive reactance loading of the diode rectifier. If the dial is set above the actual percentage modulation, the voltage input to the type 1932-A may be too low to permit normal operation of the latter, but no increase of distortion will result. In any case, an error in setting of this dial will in no way affect the readings of the type 1931-A amplitude-modulation monitor.

Because of the extremely low noise level that these instruments are capable of reading, certain precautions must be observed if full advantages are to be realized. Operation of these instruments in the presence of strong external electromagnetic fields is not advisable. Sufficient shielding has been provided for most conditions normally encountered. Some trouble may occur from power-frequency sources, giving rise to hum pick-up. Good grounding and reversing one, or both, of the power connecting cords have been found helpful in certain cases.

3. *Program Level Monitoring.* The movements of the percentage modulation indicator furnish an indication of instantaneous level that is useful for monitoring. This meter does not, however, give a true vu indication, because its ballistics must conform to different specifications which are established by the F.C.C.

4. *Transmitter Audio-frequency Response.* By applying a voltage of variable a.f. to the a-f input circuits of the transmitter, and reading the decibel scale on the percentage modulation meter for each frequency setting, the over-all a-f response of the transmitter can be determined.

6-31d. Specifications

1. *Range.* Modulation percentage, 0 to 110%, indicated by meter on positive peaks, 0 to 100% on negative peaks. The flashing lamp is adjustable to operate from 0 to 100% on negative peaks.

2. *Carrier-frequency range.* The monitor will operate at any carrier frequency from 0.5 to 60 megacycles. A single set of coils (either 0.5 to 8 megacycles or 3 to 60 megacycles) is supplied with each instrument, unless both sets are specifically ordered.

3. *Carrier-frequency input impedance.* About 75 ohms in the broadcast band, increasing slightly at higher carrier frequencies and varying somewhat with input tuning.

4. *Accuracy.* The overall accuracy of measurement at 400 cps is ± 2% of full scale at 0% and 100%, and ± 4% of full scale at any other modulation percentage.

5. *Detector linearity.* The distortion in the diode detector is very low for frequencies up to 7500 cps. Above this frequency, a small amount of negative peak clipping occurs, reaching 5% at the extreme high end of the audio range at 15,000 cps and 100% modulation.

6. *Audio-frequency response.* The frequency response of the meter indication is constant within ± 0.25 db between 30 and 15,000 cps.

7. *R-f power.* In the broadcast range the maximum r-f power requirement is about 0.5 watt.

8. *Warning lamp circuit.* The OVERMODULATION lamp will flash whenever the negative modulation peaks exceed the setting of the MODULATION PEAKS

dial by approximately 2% modulation, for audio frequencies between 30 and 7500 cps. For higher audio frequencies, the percentage overmodulation required to flash the lamp increases slightly. The accuracy of the dial calibration is approximately ± 2%.

9. *Meter circuit.* The response of the PERCENTAGE MODULATION meter is flat, within ± 0.1 db between 50 and 15,000 cps. Either positive or negative modulation peaks may be read to an accuracy of ± 2% at 0 and 100% modulation. At other modulation levels, the possible error increases to a maximum of ± 4%. The meter movement meets F.C.C. specifications for modulation monitors. Calibration in db below 100% modulation is provided.

10. *Audio monitoring output.* The audio output amplifier is flat, to within ± 1.0 db from 30 to 45,000 cps. The internal impedance is 600 ohms. Distortion is less than 0.2%. Open-circuit output voltage is about 300 millivolts.

11. *Fidelity-measuring output.* Flat within ± 1.0 db between 30 and 15,000 cps with type 1932-A distortion and noise meter connected. Output level varies inversely with setting of MODULATION PEAKS dial, thus providing reasonably uniform input to distortion meter at all modulation levels. Average output level, approximately 1.5 volts. Residual noise and hum level will not exceed − 80 db.

12. *Auxiliary output.* A multipoint connector at the rear of the instrument provides a means of connecting:

(*a*) A remote percentage modulation meter.
(*b*) Line for 600-ohm monitoring.
(*c*) The type 1932-A distortion and noise meter.

13. *Power supply.* 105 to 125 volts, 40 to 60 cps. Power input is approximately 50 watts.

14. *Dimensions.* Panel 19 × 8¾ inches. Depth behind panel 10 inches. Net weight 31 pounds.

6-32. Distortion Measurements in the Broadcasting Station—Excessive a-f distortion is annoying to the radio listener, and the difference between good-quality and poor-quality stations is easily distinguishable in modern receivers. Tests have indicated that 10 percent total harmonic distortion is about the maximum which can be tolerated if the signal is to sound reasonably pleasant to the listener. Fortunately, it is not difficult to keep distortion well below this level in transmitting and receiving equipment.

In order to ensure acceptable quality of transmission, the F.C.C. has required that no broadcast transmitter shall have more than 10 percent combined audio-harmonic distortion when operating at a level of 85 percent modulation. This has been covered in a paragraph of the F.C.C. rules governing operation of broadcast stations.

Total harmonic distortion is measured in terms of the root mean square of all the harmonics present in the output. As an example, assume that the value of the second, third, and fourth harmonics are 3 percent, 5 percent, and 2 percent respectively. The rms value would be found by taking the square root of the sum of the squares or:

$$\text{Total rms harmonic distortion} = \sqrt{3^2 + 5^2 + 2^2} = \sqrt{38} = 6.2\%$$

During recent years, transmitter manufacturers have placed considerable emphasis on freedom from distortion and, as a result, transmitters are now available with distortion levels as low as 2 percent. Complete performance characteristics of all transmitters intended for general sales are submitted to the F.C.C. as proof that the requirements are being met.

Holding distortion at a low figure has consequently become a problem of maintenance rather than of transmitter design. In the carefully balanced electrical circuits that make up the modern transmitter, changes in the operating voltages and the characteristics of vacuum tubes, as well as the slow aging of other circuit elements, may result in excessive distortion. Proper care and maintenance are necessary to obtain consistently good performance. Periodic measurements are the obvious safeguard against excessive distortion and, when made as part of a definite maintenance routine, they add very little to the duties of the operating staff. Simple measurement methods and direct-reading instruments have greatly reduced the time required for such measurements.

6-33. The General Radio Type 1932-A Distortion and Noise Meter—The type 1932-A distortion and noise meter is designed for use in measuring a-f distortion, noise level, and also vu level in a 600-ohm line. Input impedance is selected by means of a panel switch, and may be either 100,000 ohms unbalanced, or a 600-ohm bridging impedance of approximately 10,000 ohms, which may be operated balanced or unbalanced. Vu level is indicated for a reference level of one milliwatt in a 600-ohm line, and the range extends from + 20 to − 60 vu. When used in connection with the type 1931-A modulation monitor, complete transmitter modulation characteristics may be measured.

6-33a. Principles of Operation—1. *Distortion Measurements.* The instrument consists essentially of a continuously variable null network, followed by a calibrated vacuum-tube voltmeter. The fundamental frequency of the signal being measured is balanced out by means of two panel controls; all other components remain and are passed on directly, and without attenuation, to the voltmeter. Thus, if the voltmeter is first set to 100% with the entire signal voltage present, an arbitrary reference level is established. Upon switching in the null network, to remove the fundamental frequency only, a second reading may be obtained on the voltmeter scale. This second reading is composed of all distortion

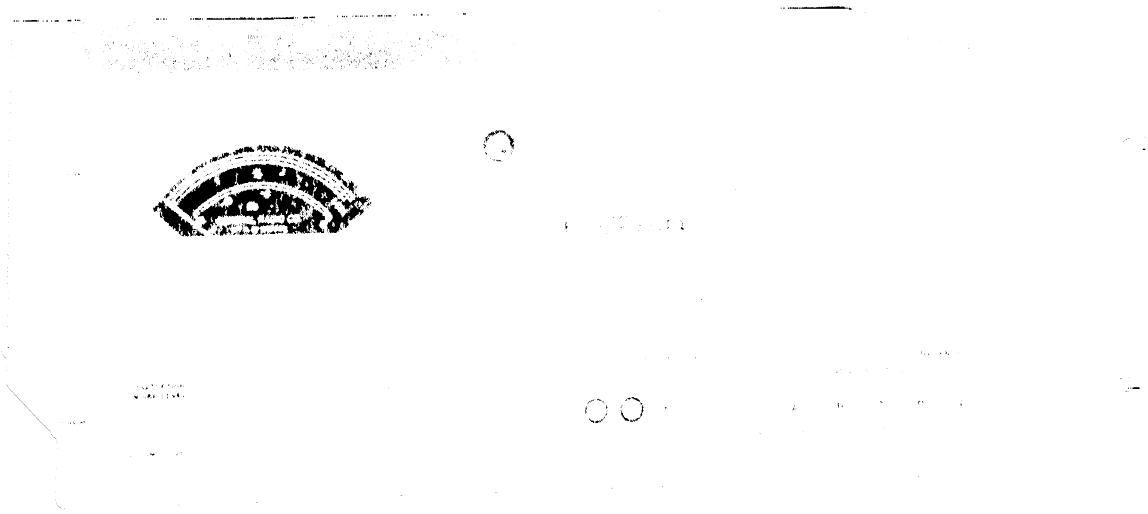

FIG. 6–43. The General Radio type 1932-A noise and distortion meter.

products present, plus extraneous noise and power-supply hum frequencies. Since the ratio between the two readings may be observed by means of the voltmeter attenuator, this becomes a measure of the distortion, and/or noise products present in the signal, expressed as a percentage of the total signal.

2. *Noise Level.* The instrument is used in this position as a calibrated, sensitive, vacuum-tube voltmeter. To determine the noise level in a system, the sensitivity is set to give 100%, or full-scale reading on the meter. If the audio signal is then turned off, and the voltmeter sensitivity increased until a reading is again obtained on the meter scale, the ratio between the two attenuator settings becomes a measure of the signal-to-noise ratio, or noise level.

3. *VU Level Indicator.* When the instrument is set to the vu position, it reads the level directly in vu for a 600-ohm line. The BRIDGING INPUT position must be used, and may be operated from a balanced or unbalanced 600-ohm line. The instrument is directly calibrated to read from +20 to − 60 vu, with a reference level of 0 vu equal to 1.0 milliwatt in 600 ohms.

The ballistic characteristics of the meter are made to correspond to the standard characteristics for volume-level indicators, that is, reading will reach 99% of steady-state value in 0.3 second.

6–33b. Range and Accuracy—1. *Distortion.* Distortion is indicated directly on the meter, which is provided with two scales calibrated in percent. Full-scale values of 100, 30, 10, 3, 1, and 0.3% may be selected by a switch. Readings are accurate to within ± 5% of full-scale, ± 0.05% distortion.

The frequency range is continuously variable for any fundamental frequency between 50 and 15,000 cycles. The readings of the main frequency dial are accurate to ± 2%. The response is flat, within 1 db, from the second harmonic of the fundamental frequency up to 45,000 and also from one-half of the fundamental frequency down to 30 cycles.

The input signal level should be between 1.2 and 30 volts for the 100-kilohm input, or 0.8 and 30 volts for the 600-ohm bridging input. For higher signal levels, an external attenuator should be used.

2. *Noise Level.* Noise levels between the limits of 0 to − 80 db may be measured satisfactorily with this instrument. The response is flat, within 1 db, between 30–45,000 cycles.

Signal applied to the input terminals may be between 1.2 and 30 volts for 100-kilohm input, or 0.8 and 30 volts for the 600-ohm bridging input. For higher signal levels, an external attenuator should be used.

3. *VU Level.* The range extends from + 20 to − 60 vu, from a reference level of 1.0 milliwatt (0.775 volt) in a 600-ohm line. Frequency response is flat within 1.0 db from 30 to 45,000 cycles.

4. *Meter Characteristics.* The indicating meter circuit employs an average response type, diode vacuum-tube voltmeter.

6–33c. Installation and Operation—1. *Power Supply Connections.* The instrument may be connected to any source of 115/230 volts, 50–60 cycle supply, via the connector cord provided. Internal voltage-regulator tubes will stabilize the instrument against the effects of line-voltage variations between the limits of 105–125 volts (210–250 volts). A split-primary winding on the power transformer provides for operating the instrument from a 230-volt line by a simple tap-changing operation. As normally supplied, the instrument is set up for 115-volt operation. To change to 230-volt operation, it is merely necessary to alter the transformer taps so that terminals 2 and 3 are connected together. (For 115 volts, connect 1 to 3, and 2 to 4.)

The line-voltage plate is reversible, for 115 or 230 volts, and should agree with the transformer connections as made.

2. *Audio Input Connections.* A standard W.E. panel jack provides a convenient means for making connection to the instrument from the front of the unit. When this is done, it automatically disconnects a rear Jones plug, to which more permanent connections may be made.

An INPUT switch is located near the center of the panel and provides a means of selecting an input impedance of either 100,000 ohms or the 600-ohm bridging impedance of approximately 10,000 ohms. The latter may be operated balanced to ground, if desired, or with either side connected to ground.

3. *Distortion Measurements.* Having selected the desired input conditions, set the meter to the CAL mark on the scale by adjustment of the CAL control on the panel. Both panel switches should be set at the points marked CAL.

Depress the DIST switch, and set the main dial and range switch to agree with the fundamental frequency of the signal under test. Tune the R and C balance controls, simultaneously, until a minimum is read on the meter. The meter scale switch should be changed as necessary to keep the deflection at a readable point on the scale.

The initial adjustments can be made quite rapidly. If the signal under test is low in distortion, and the 0.3% full-scale range of the meter is used, reasonable care will be required to balance accurately the R and C controls for an absolute minimum. The resulting indication is the average distortion in percent as read from the meter scale.

When operating on the 0.3% full-scale range, the meter may tend to show erratic variations if the source of signal frequency is unstable or affected by line voltage surges. Use of a line-voltage regulator on the system under test is recommended for such conditions. For normal conditions, it should not be necessary to provide an external line-voltage regulator for the type 1932-A distortion and noise meter.

Several distortion measurements, at various frequencies, may be made without the need for the calibration step being repeated each time, provided the input signal is kept at constant amplitude.

4. *Noise Level Measurements.* The initial calibration procedure is the same as for distortion measurements. When this has been done, turn off the signal at its source and increase the meter sensitivity via the panel switch, until an indication is obtained on the meter. The arithmetic sum of the meter reading in db and switch position in db is the average value of the signal-to-noise ratio. The METER READS switch remains in the NOISE position throughout the test.

5. *VU Level Measurements.* When used to measure the signal level in a 600-ohm line, the METER READS switch is set to the VU position, which simultaneously depresses the 600-ohm BRIDGING INPUT switch. The circuit is internally calibrated to read the signal level directly in vu, and is independent of all other panel controls. Thus it is possible to quickly measure the vu level at any time by merely depressing the switch and observing the meter reading in vu, plus the reading of the meter switch. The absolute vu level is the arithmetic sum of the meter reading and the calibration, in VU, on the meter switch.

6–33d. Adjustments and Maintenance—1. *Distortion Calibration.* A potentiometer is provided to permit the calibration of the distortion measuring circuit. Its function is to compensate for the "insertion loss" of the null network, at frequencies in the "pass band." Its setting is accomplished merely by making the readings of the meter equal, for NOISE AND DIST position of the METER READS switch, when the main frequency dial is set at a point *removed* from the applied frequency by an amount equal to, or greater than, the second harmonic of this frequency. (*Example:* Let the signal frequency be 1000 cycles, then the dial may be set anywhere in the range above 2000 cycles. Depress the NOISE switch and note the meter reading. Now depress the DIST switch and adjust the compensating potentiometer until the same meter reading is obtained.)

This adjustment is made initially at the factory and should not normally require correction.

2. *Calibration of VU Level.* A potentiometer is provided for this purpose. Its function is to set the gain of the amplifier so as to provide a reading of 0 vu, when a voltage of 0.775 volt (1.0 milliwatt in 600 ohms) is applied to the 600-ohm bridg-

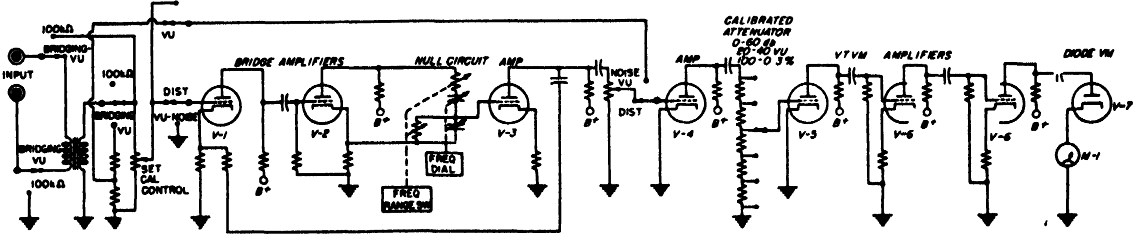

Fig. 6–44. Elementary schematic diagram of the type 1932-A distortion and noise meter.

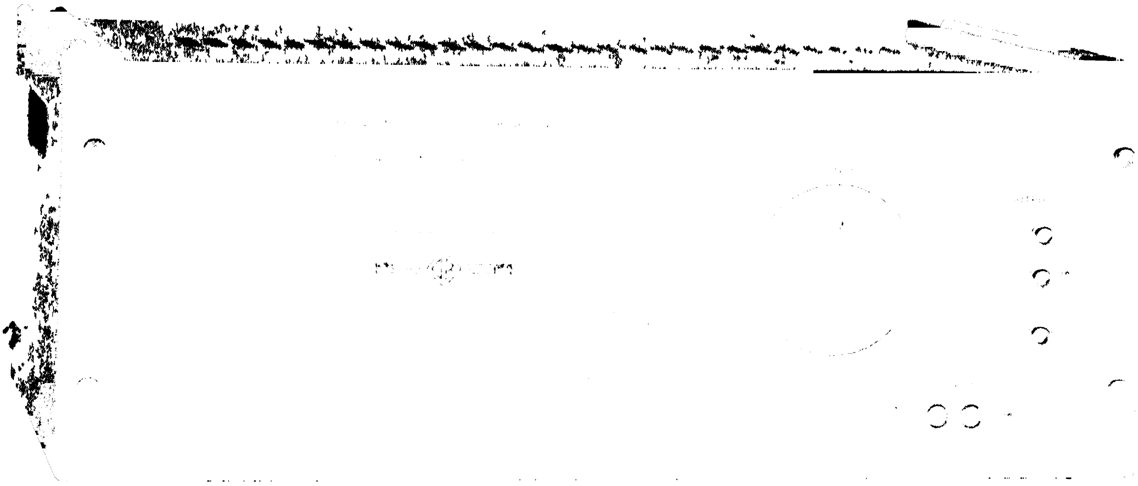

FIG. 6–45. The General Radio type 1301-A low distortion oscillator.

ing input terminals. This may be checked at any time by using an accurately calibrated voltmeter or volume-level indicator, as a reference standard.

This adjustment has been pre-set at the factory and should not normally require correction.

3. *Tube Replacements.* The instrument is substantially free from variations in tube characteristics. All normal tubes will work satisfactorily. Should it prove necessary to replace V–1, V–2, or V–3, it may be desirable to check the adjustment outlined in (1) above. Replacement of V–4, V–5, V–6, or V–7 may make it desirable to check the vu calibration, as outlined in (2) above.

4. *Precautions.* Because of the inherently high gain of the internal amplifiers, difficulties due to a-c hum pick-up, stray fields, etc., may be encountered unless certain rules are followed. The instrument should not be operated in the vicinity of strong electromagnetic fields, such as may be found near equipment containing saturating-core regulating transformers, etc. The 600-ohm input will be most sensitive to this type of interference. Grounding the panel securely is highly desirable, and in some locations where an unbalanced a-c supply line is found, it may help to try reversing the a-c input-power cord. When the instrument is operating properly, the hum should not be visible as a deflection above −20 db on the meter scale when the meter switch is set at the −60 db position, with no connections to the input when the 100-kilohm position is used. The BRIDGING input may be similarly checked, except that a dummy 600-ohm load must be connected to the input terminals. If, when an external lead is connected to the input terminals, the reading increases, it is an indication of pick-up on the connecting leads. Use of shielding on all connecting leads is desirable.

Should hum be present when distortion and/or noise measurements are made, the resulting readings will tend to be somewhat higher than the actual value.

6–33e. R-f Applications—When the type 1932–A distortion and noise meter is used in conjunction with the type 1301–A low-distortion oscillator and the type 1931–A modulation monitor, the complete audio-modulation characteristics of a transmitter may be measured. The oscillator is used to apply a modulation of extremely low initial distortion to the transmitter. The modulation monitor provides a means of measuring percentage modulation and also has an internal linear-diode detector and amplifier, which may be used to supply an undistorted signal to operate the type 1932–A distortion and noise meter. Cables are provided for all necessary interconnections at the rear of the instruments, and may be left permanently connected. Convenient panel jacks permit individual use of each instrument, by electrical disconnection of the rear plugs when the panel plug is inserted.

6–33f. Specifications

1. *Distortion range:* Distortion is read directly from a large meter. A multiplier allows full-scale deflections for 0.3%, 1%, 10%, or 30% distortion.

2. *Noise measurement range:* The range for carrier noise measurements extends to 80 db below 100% modulation, when the distortion meter is operated from the type 1931–A modulation monitor, or 80 db below an audio-frequency signal of zero vu level.

3. *Audio-frequency range:* 50 to 15,000 cps (fundamental) for distortion measurements; 30 to 45,000 cps for noise and hum measurements.

4. *VU range:* The power-level range is from +20 to −60 vu. Full scale values of +20, +10, 0, −10, −20, −30, and −40 vu are provided. The scale is calibrated in terms of a reference level of one milliwatt in 600 ohms.

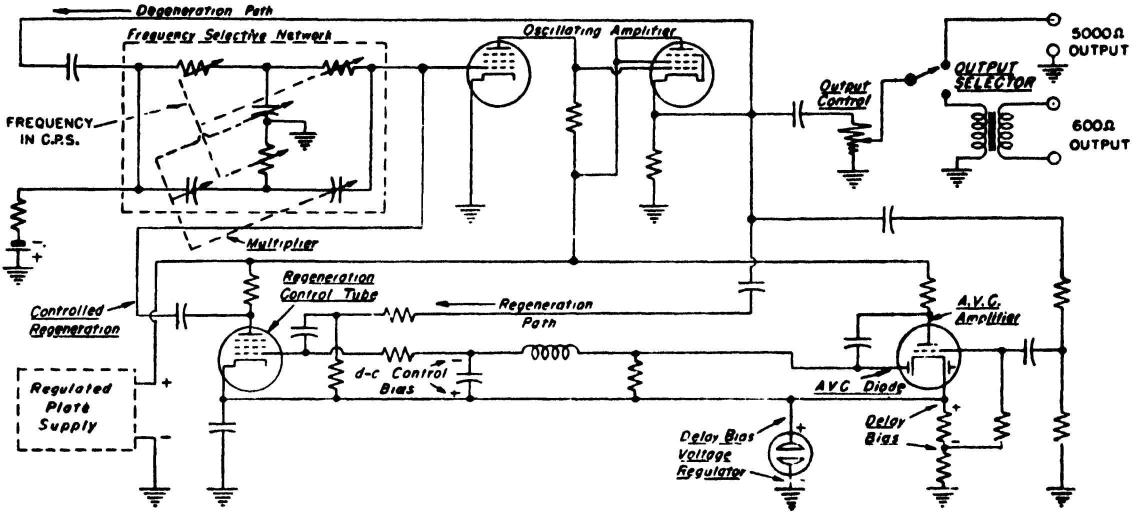

Fig. 6–46. Elementary schematic circuit diagram of the type 1301-A low-distortion oscillator.

5. *Input voltage range:* The input signal level should be between 1.2 and 30 volts for the 100-kilohm input, and between 0.8 and 30 volts for the 600-ohm bridging input.

6. *Accuracy:* For distortion measurements, ± 5% of full scale for each range ± residual distortion as noted below; for noise and vu measurements, ± 5% of full scale.

7. *Input impedance:* Two input impedances are provided, 100,000 ohms balanced, and 600-ohm bridging input (10,000 ohms), balanced or unbalanced.

8. *Residual distortion level:* 100-kilohm input: 0.05%, maximum, below 10,000 cps; 0.10%, maximum, above 10,000 cps. Bridging input: 0.10%, maximum, between 50 and 70 cps; 0.05%, maximum, between 70 and 10,000 cps.; 0.10%, maximum, above 10,000 cps.

9. *Residual noise level:* Less than — 80 db.

10. *Accessories required:* For measuring the distortion in oscillators and other audio-frequency sources, no additional equipment is required. For measurements on amplifiers, lines, and other communication networks, a low distortion oscillator is required to furnish the test tone. Type 1301–A low distortion oscillator is recommended. When the modulated output of a radio transmitter is to be measured, a linear rectifier to produce the audio envelope is necessary. The type 1931–A modulation monitor is recommended for this purpose. However, any detector system having an undistorted output of 1.5 volts rms can be used.

11. *Terminals:* Input terminals are provided at the rear of the instrument for direct connection to the modulation monitor. A Western Electric jack is provided at the panel also, as an auxiliary input circuit. Plugging into this jack automatically disconnects the rear connectors.

12. *Power supply:* 105 to 125, or 210 to 250 volts, 40 to 60 cps. The line input power is 60 watts. The power supply is voltage regulated. Line surges will have no appreciable effect, except when the instrument is operated on the 0.3% distortion or —60 db scale.

13. *Dimensions:* Panel 19 × 7 inches; depth behind panel, 12 inches. Net weight, 35½ pounds.

6–34. General Radio Type 1301–A Oscillator—The type 1301–A oscillator was designed particularly for use as a tone source for distortion measurements and as a power source for bridge measurements at audio frequencies. Because of the large number of frequencies at which this oscillator will operate, it is also satisfactory for measuring frequency characteristics and for use as a general laboratory oscillator.

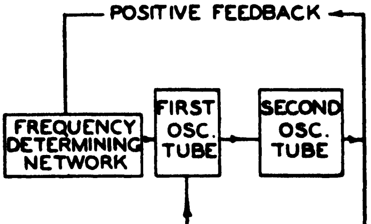

Fig. 6–47. Block diagram of oscillator section.

The output frequencies include those recommended by the F.C.C. for distortion measurements on broadcast transmitters. This oscillator is thus ideal for use with the type 1932–A distortion and noise meter for rapid distortion measurements.

The unusually pure wave form delivered by this oscillator at low frequencies makes distortion measurements possible at considerably lower frequencies than have hitherto been practicable.

6–34a. Description—The oscillator is of the resistance-tuned type and operates on the inverse feedback [9] principle developed by the General Radio Company. Separate feedback networks control the frequency and amplitude independently, thus providing high stability and low distortion.

The degenerative feedback which controls the frequency is obtained by means of a parallel-T network including mica condensers and wire-wound resistors. The regenerative network includes a new automatic control system whereby a high degree of stability is obtained together with low harmonic distortion, without the need for any manual feedback adjustments.

The desired frequency is selected by push-button switches. Another push-button switch selects the output impedance. A control is provided for adjusting the output voltage.

6–34b. Features—The important features of this oscillator are high stability and low distortion. A distinctive convenience feature is the push-button control which allows instant selection of any one of 27 frequencies from 20 to 15,000 cycles.

Jacks are provided for plugging in external resistors, thus allowing the operation at any frequency within the nominal operating range. In addition, satisfactory operation can be obtained at frequencies outside of this range and as low as 2 cycles, at some sacrifice in purity of waveform.

An external range-extension unit, type 1301–P1, is available which plugs into the oscillator and provides a multiplying factor of 0.1 for all frequencies, thus extending the frequency range downward by a full decade (2 to 15 cycles).

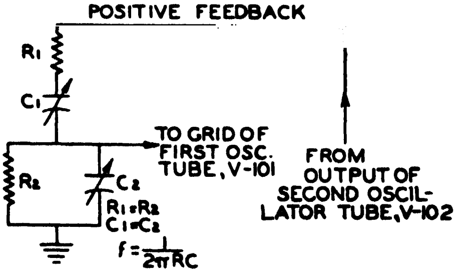
POSITIVE FEEDBACK
R1
C1
TO GRID OF FIRST OSC. TUBE, V-101
FROM OUTPUT OF SECOND OSCILLATOR TUBE, V-102
R2
C2
R1=R2
C1=C2
f=1/2πRC

Fig. 6–48. Simplified diagram of frequency-determining network.

6–34c. Specifications

1. *Frequency range:* 27 fixed frequencies between 20 and 15,000 cps.

2. *Frequency control:* The frequency is controlled by two push-button switches. The first provides frequencies of 20, 25, 30, 40, 50, 60, 75, 100, and 150 cps, while the second multiplies these frequencies by 1, 10, and 100. The frequencies included cover practically the entire audible range in approximately logarithmic increments.

3. *Frequency calibration:* Each instrument is adjusted within ± 1% ± 0.1 cycle.

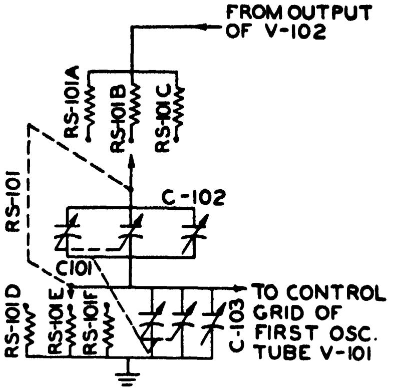

Fig. 6–49. Frequency-determining network.

4. *Frequency stability:* The internal voltage regulator eliminates frequency changes resulting from changes in plate supply. Changes in load have no effect upon the frequency. The frequency drift is not greater than 0.02% per hour after the first 10 minutes of operation.

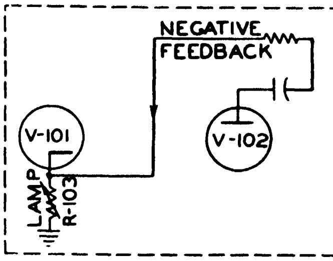

Fig. 6–50. Negative feedback circuit used in the oscillator section.

5. *Output impedance:* Three output circuits are provided. Selection among them is obtained by means of a push-button switch on the panel. The output impedances are as follows:

(*a*) 600-ohm balanced to ground.
(*b*) 600-ohm unbalanced.
(*c*) 500-ohm unbalanced.

The volume control is a potentiometer in the 5000-ohm circuit. The actual output impedance of the 5000-ohm circuit will vary between 1000 and 6000 ohms, depending upon the setting of the volume control. Suitable resistance pads keep the impedance of the 600-ohm output circuit essentially constant, regardless of the volume control settings. The 600-ohm balanced output circuit is balanced at all frequencies when operating into a balanced load of any impedance.

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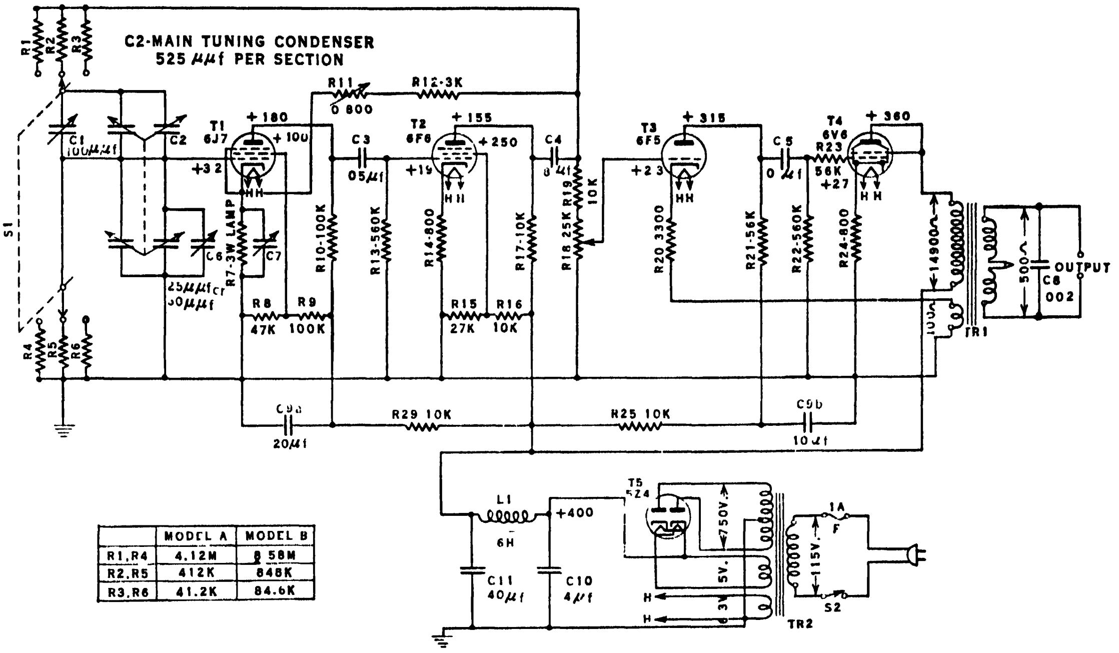
[9] U. S. Patent No. 2,173,427.



	MODEL A	MODEL B
R1,R4	4.12M	8 58M
R2,R5	412K	848K
R3,R6	41.2K	84.6K

FIG. 6–51. Schematic circuit diagram of Hewlett-Packard resistance tuned oscillator.

6. *Output power:* 15 milliwatts into 600-ohm load or 6-volt open circuit; 80 milliwatts into 5000-ohm load or 30-volt open circuit.

7. *Waveform:* (*a*) 5000-ohm output: Not more than 0.1% between 40 to 7500 cps. Not more than 0.15% at other frequencies: (*b*) 600-ohm output: Not more than 0.1% between 40 to 7500 cps. Not more than 0.25% between 20 to 40 cps. Not more than 0.15% above 7500 cps.

8. *Power supply:* 105 to 125 (or 210 to 230) volts, 50 to 60 cps a.c. The total power consumption is approximately 45 watts.

9. *Dimensions:* Panel 19 × 7 inches; depth behind panel, 12 inches.

6–35. Hewlett-Packard Resistance-tuned Audio Oscillator—The Hewlett-Packard resistance-tuned audio oscillator is basically a two-stage, resistance-coupled amplifier. It oscillates by virtue of the fact that a portion of the output voltage is fed back to the input of the amplifier in the proper phase relation (positive feedback). In addition, negative feedback is employed to stabilize the operation of the oscillator and to keep the output constant over a wide range of frequencies. A block diagram of the oscillator section is shown in Figure 6–47.

The frequency-determining network preceeds the input to the first oscillator tube V–101. Figure 6–48 shows a simplified schematic diagram of this network. The design of the system is such that the voltage applied to the first oscillator control grid is in phase with the voltage applied to the whole frequency-determining network. In addition, the grid voltage is always one-third of the voltage applied to the whole network.

The network's resonant frequency is inversely proportional to the product of the resistance and capacitance. From this it may be seen that large changes in resonant frequency are possible for a given set of components. A frequency change of more than 10 to 1 is provided by each set of resistors. The entire audio spectrum is covered by using three separate sets of values for *R*. The complete frequency-determining network is shown in Figure 6–49.

As may be seen in the simplified diagram, Figure 6–50, the negative feedback voltage used in the oscillator section is derived from the output of the second oscillator tube V–102 and is fed back to the cathode of the first oscillator tube V–101. The magnitude of the negative feedback is determined by a resistor network, one element of which is the incandescent lamp R–103. A property of this lamp is that it has a positive temperature coefficient; however, it possesses sufficient thermal inertia so that its temperature is substantially constant even at frequencies as low as 6 cycles. Because of this nonlinear property, the oscillations cannot build up to large values, for, if the oscillations tend to build up, the resistance of the lamp tends to increase, and therefore the degeneration increases, causing less amplification in the oscillator section. Thus, the lamp selects the proper operating point for the system and serves as an automatic amplitude limiter.

CHAPTER 7

FREQUENCY MODULATION SYSTEMS

While several papers had been published on the aspects of both frequency and phase modulation, it was not until Major Edwin H. Armstrong demonstrated his development of a system in 1933–34 that the advantages of frequency modulation in overcoming atmospheric and man-made noises, as well as improvements in fidelity and other possibilities, were realized. Major Armstrong's demonstration of interference-free reception during the presence of local thunderstorms was startling and fascinated radio engineers and experimenters throughout the world.

Subsequently, Murray G. Crosby secured a patent[1] disclosing a type of frequency modulator wherein a high degree of stability was maintained by the use of automatic frequency control circuits similar to those incorporated in some broadcast receivers. In this system, the same controlling means used to produce the frequency modulation is also employed for automatically controlling the mean frequency of the modulation. In this way, a simple frequency modulator with a high degree of stability is obtained without the necessity of a high degree of frequency multiplication.

7–1. Requirements of an F–M System—As in amplitude modulation, side-band frequencies are transmitted but, in general, are quite different, since in amplitude modulation one pair of side bands is produced, whereas in frequency modulation an infinite number of side bands is produced.

Good engineering practice requires that the following conditions be satisfied to insure that the maximum advantages are derived from frequency modulation.

1. The frequency deviation must take place around a fixed point, the mean carrier frequency, and during modulation the change in frequency must be symmetrical with respect to this point. Over periods of time, there must be no drift from the mean carrier frequency.
2. The frequency deviation of the transmitted wave should be independent of the frequency of the modulation current and directly proportional to the amplitude of that current.
3. The receiving system must have such characteristics that it will convert changes in frequency to changes in amplitude. The bandwidth of the receiving system must be capable of passing the complete deviation of frequency each side of the carrier.
4. The amplitude of the detected current should be directly proportional to the change in frequency of the transmitted wave and independent of the rate of change thereof.

From these conditions, it can be stated that a frequency-modulation transmission system requires that the frequency of the carrier be varied in accordance with audio-modulating frequencies at a rate proportional to the frequency of the audio-modulating signal, and that the amount of deviation be proportional to the amplitude of the audio-modulating signal.

Because of the wide frequency band required, operation of F–M systems is necessarily confined to the very high frequencies and, in general, to frequency bands above 30 mc.

7–2. Modulation Characteristics—A graphical comparison of the waveform of an amplitude and frequency modulated wave will be helpful in understanding the mechanics of frequency modulation as compared to amplitude modulation. Referring to Figure 7–1, line (a) shows the carriers of both systems without modulation. Line (b) shows the carriers modulated by an audio-frequency sine wave. It will be noted that in the case of amplitude modulation, the amplitude of the carrier is varied in accordance with the audio-modulating frequency, but the intervals between each cycle remain unchanged. In other words, no change in the frequency of the carrier has been made. However, a glance at the frequency-modulation pattern will disclose intervals of different lengths indicating that the frequency has been changed, but each cycle maintains the same amplitude.

7–3. The Armstrong System—Since the Armstrong or "indirect system" obtains its frequency modulation through the use of a phase modulator, an understanding of the difference between phase and frequency modulation is necessary to understand the Armstrong system fully.

With a sine wave for a modulating signal and the amplitudes properly adjusted, the resulting frequency spectra from both phase and frequency modulation will be identical. However, if a new modulating frequency is substituted in the two systems, it will be necessary to readjust the amplitude of the modulating signal in the phase-modulated system to make them identical again. It is found that the angle of phase shift in the phase-modulated system must be inversely proportional to the modulating frequency to produce the spectrum of a frequency-modulated system in which the frequency

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[1] U. S. Patent Office No. 2,279,659, April 14, 1942. Murray G. Crosby assignor to Radio Corporation of America.

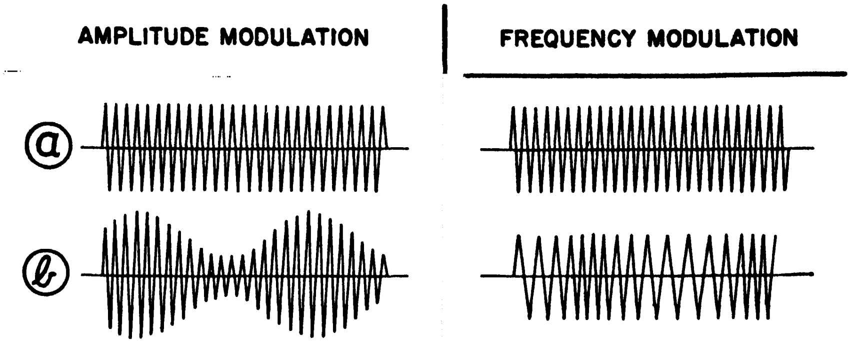

Fig. 7–1. Waveform of an a-m and f-m signal.

deviation is independent of the modulating frequency. If the audio response of the modulating system is made inversely proportional to frequency over the desired audio-frequency response range of the system, true frequency modulation will be produced.

If a small portion of the output of an oscillator has its phase changed by ±90° and this quadrature component is added to the principal output of the oscillator, the resultant output differs in phase from that of the oscillator by an angle approximately equal to the ratio of the quadrature part to the principal part of the combined currents. If the amplitude of the quadrature current is made proportional to the amplitude of a desired modulating frequency, a system of phase modulation will result. It is found that modulations of the phase angle exceeding 30° cannot be made by this system without creating excessive distortion. A relatively simple circuit is available to produce phase modulation in this manner. The operation of the system can be explained by referring to the schematic circuit arrangement of Figure 7–2.

A voltage derived from the crystal oscillator is applied in like phase to the grid of an amplifier, and both grids of a balanced modulator. The plate circuits of the modulators are made nonreactive for the frequency applied to their grids by balancing out the reactance of the transformer primaries by means of the condensers in series with the windings. The plate currents are, therefore, in phase with the voltage applied to the grids. The succeeding amplifier (side-band amplifier) is inductively coupled to the balanced modulators, the secondary of the coupling transformer having a natural period that is high compared with the frequency of the crystal oscillator; thus the excitation to the side-band amplifier always differs in phase by 90° from the output of the crystal oscillator. When the modulator tubes are unbalanced by the application of a signal to their screen grids, they pass a portion of the oscillator output which furnishes a quadrature excitation for the side-band amplifier. Therefore, the voltages that both the frequency amplifier ($V1$) and the side-band amplifier ($V3$) develop across the common resistance load used to excite the next amplifier will be 90° apart.

The phase of the voltage across the common resistance of the two amplifiers is alternately advanced and retarded by the combination of the modulated and unmodulated components and the maximum phase shift is given by an angle whose tangent is the sum of the peak value of the quadrature component divided by the peak value of the unmodulated component. By keeping this angle sufficiently small (not greater than 30°) it may be made substantially proportional to the amplitude of the two side frequencies and hence to the amplitude of the initial modulating current.

To insure a frequency deviation independent of the modulating frequency, it is necessary to take measures to make the angle through which the phase is shifted inversely proportional to the frequency of the modulation current. This is accomplished by employing a correction network in the audio amplifier preceding the modulators as shown in Figure 7–3. The design of this network is such that the amplification characteristics are inversely proportional to frequency. The condenser C_1, whose impedance for the lowest frequency of modulation is relatively small with respect to the series resistance R_2, makes the voltage on the grid of the amplifier tube inversely proportional to the frequency. Consequently, the angle through which the current in the phase modulator is advanced or retarded becomes directly proportional to the amplitude of the modulation current *and inversely proportional to its frequency.* The resulting phase shift, which in practice is limited to 30° when the modulation frequencies extend from 50 to 15,000 cycles, must be multiplied a great many times before the desired deviation of frequency is obtained to insure reception free of interference. The initial frequency deviation is of the order of 15 to 20 cycles at a fundamental frequency of 200 kc. As employed in F–M broadcasting, it would be necessary to multiply the initial deviation and fundamental frequency 50,000 times. This is accomplished, as

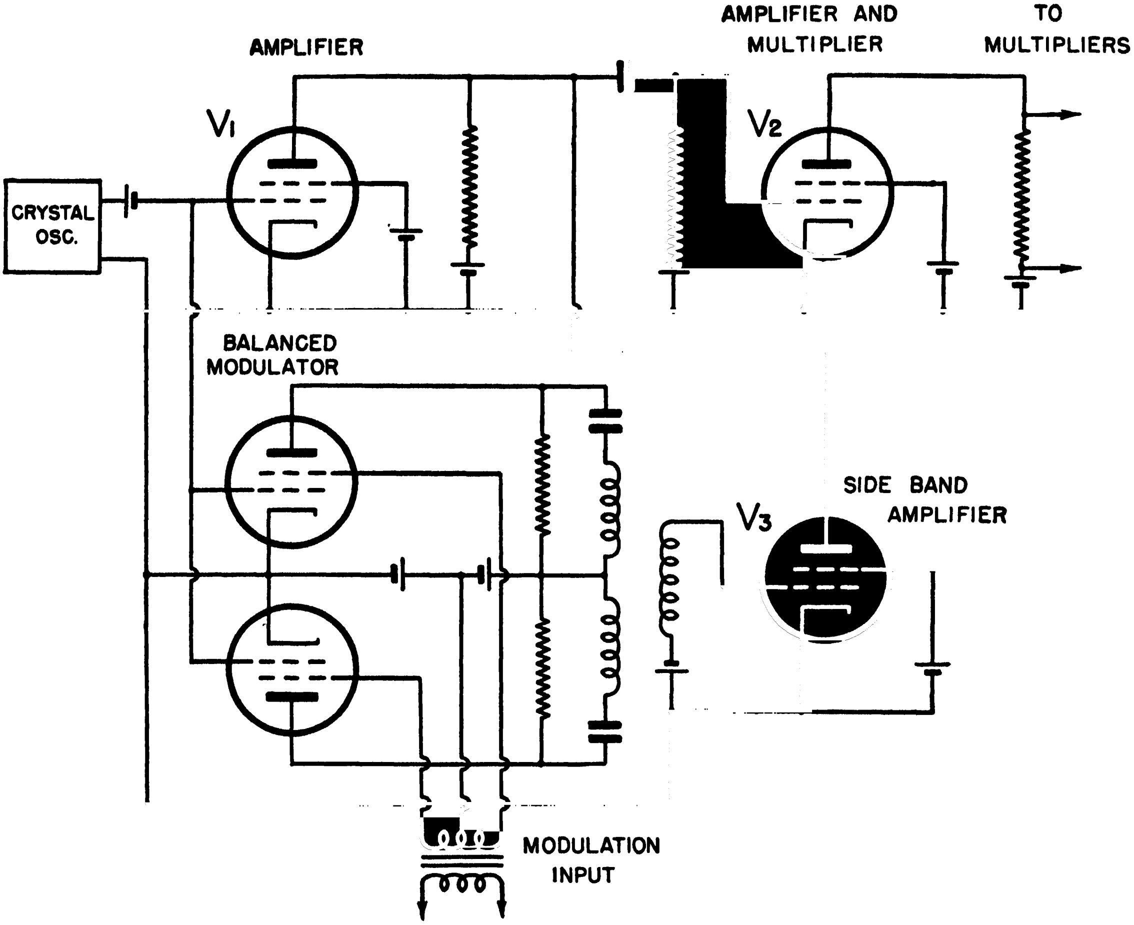

FIG. 7–2. The Armstrong system of frequency modulation.

stated previously, by a series of frequency multiplier stages, the initial stages of which may employ receiving type tubes until the desired deviation and excitation power for larger transmitting tubes are obtained.

7–4. Frequency Control—A modification of the original methods of controlling the carrier frequency of an F-M transmitter using the Armstrong system of modulation, as employed in REL transmitters, is shown graphically in Figure 7–4. The operation of this system is described by REL as follows:

"The distinguishing feature of this method, as compared to others, is that the modulation of the frequency of the transmitter is accomplished without affecting in any way the frequency of the controlling oscillator. This is done basically by varying the amplitude of one of two currents that are phased at 90°. The resultant is consequently modulated both in frequency and phase. In order that the ultimate frequency deviation of the carrier shall be independent of the audio-modulating frequency, the program is passed through a corrector network, the response of which is inversely proportional to frequency. Referring to the block diagram, Figure 7–4, this network is located in the output of the audio panel. By virtue of the balanced modulator arrangement of the modulator panel, there are produced

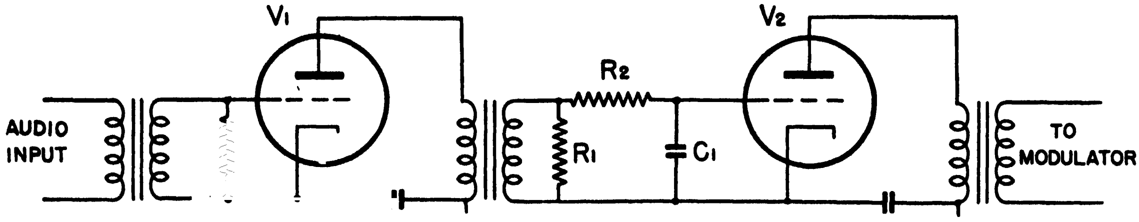

FIG. 7–3. Frequency correction network.

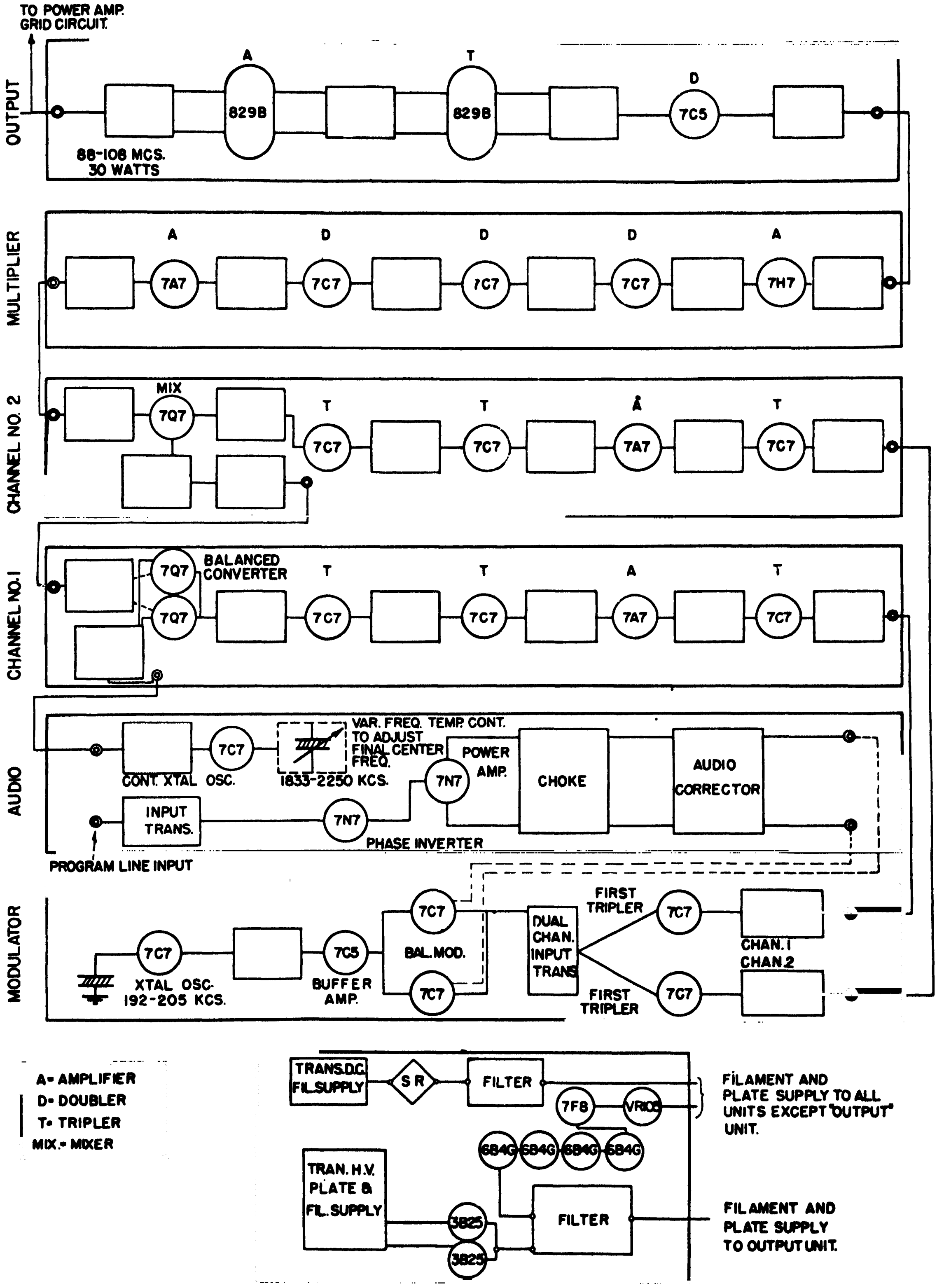

FIG. 7–4. Block diagram of the dual channel modulator.

two frequency-modulated currents whose deviations are instantaneously in opposite directions. The source of the current at the modulating frequency is a crystal oscillator operating at about 200 kc. The two oppositely modulated signals are multiplied in frequency 81-fold in two separate channels; hence, Dual Channel. One of these is heterodyned to another frequency about 2 mc removed. This resultant, and the output of the other multiplier channel, are then beat together and their difference recovered. At this point, all dependence of the output frequency of the transmitter on the original 200-kc oscillator is removed and its place is taken by the crystal oscillator operating at 2 mc located in the modulator panel. The actual heterodyning occurs in the channel No. 1 panel. It should be observed that this latter is in no way affected by modulating currents, and that it can be, and is, designed with but one object in view—stability. The remaining frequency multiplication in the modulator is 48-fold and occurs in multiplier and output panels. The ultimate frequency stability of the transmitter, as the result of this arrangement, is as though the carrier had not been frequency modulated and is therefore directly comparable to that of an A–M transmitter at the same final frequency. The simplicity and directness of this method of frequency control are unique. There are no tuning motors, reactance tubes, d-c control circuits, or free oscillators."

7–5. Deviation Ratio, or Index of Modulation—In amplitude modulation we express the degree of modulation in terms of percent. In frequency modulation the degree of modulation is called the deviation ratio, or index of modulation. The deviation ratio is defined as the maximum deviation of the frequency from its center or mean frequency divided by the modulating frequency. As an example, consider an F–M broadcast station operating with a maximum frequency deviation of ± 75 kc and with a modulating frequency of 15,000 cycles; the deviation ratio equals 75/15, or 5.

The Federal Communications Commission in its "Standards of Good Engineering Practice" covering the operation of high-frequency broadcast stations on the basis of 200-kc channel separation has specified ± 75 kc as 100-percent modulation for an F–M broadcast station. This permits sufficient frequency swing to obtain good noise reduction and, at the same time, leave a margin as a guard band to prevent adjacent channel interference.

Summarizing, it can be said that the measurement of percentage of modulation or deviation ratio in F–M broadcasting is a measurement of the range of instantaneous frequency deviation with 75 kc as 100 percent.

Figure 7–5 shows the distribution of the carrier and the side bands as a function of the deviation ratio. For simplicity, only the components up to the fourth side band and deviation ratios up to ten are shown. The negative values on these curves simply mean a reversal of phase. It should be noted that the amplitude of the side bands bears no simple relationship to the magnitude of the modulation as in an amplitude-modulated system.

7–6. Relation of Highest Modulation Frequency to Carrier—In the phase-shifting system of the balanced modulator just described, an important consideration is involved when the modulation frequencies are high compared with the fundamental oscillator. The plate circuits of these tubes are substantially aperiodic, and consequently the amplitudes of the upper and lower side-band frequencies are approximately equal; therefore, the voltage developed in the secondary of the coupling transformer is directly proportional to the value of these frequencies. In the case where the fundamental frequency is 50,000 cycles and the modulation frequencies are 10,000 cycles or higher, the upper side frequency may be 50 percent greater than the lower. Here, again, this inequality of frequencies may be compensated for by inserting a correction network of capacitance and resistance of proper values subsequent to the point at which the combination of carrier and side frequencies is effected but prior to the point at which loss of linearity of amplitude occurs. It is necessary to keep the level of the amplifiers ahead of the compensating network sufficiently low to insure linear operation.

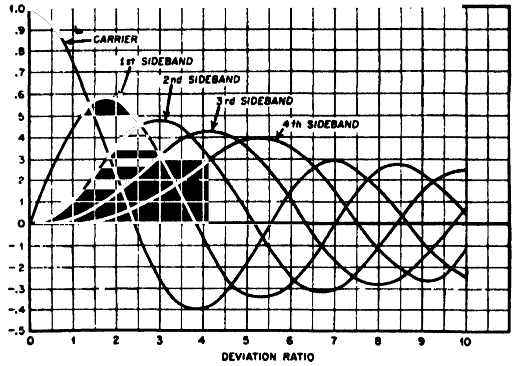

Fig. 7–5. Distribution of the components of an f-m signal. (Courtesy Radio Magazines, Inc.)

7–7. Reactance Modulation—The "direct system" of producing frequency modulation patented by Crosby utilizes a reactance modulator tube connected in parallel with the oscillator tank circuit, permitting the modulating frequencies to produce an effective change of inductance of the oscillator tank circuit.

In such a circuit arrangement, the transmitter output may have its frequency modulated without the need of frequency multipliers. In practice, however, frequency multipliers are used, and consequently the deviation, or carrier swing, is likewise multiplied by the degree of multiplication.

Since such a system cannot have its carrier frequency crystal controlled, it is necessary to utilize carrier frequency control by the method shown in Figure 7–6. In this circuit arrangement, a small part of the carrier frequency is heterodyned in a converter tube with the output of a crystal oscillator through a tripler circuit so that a difference of 1000

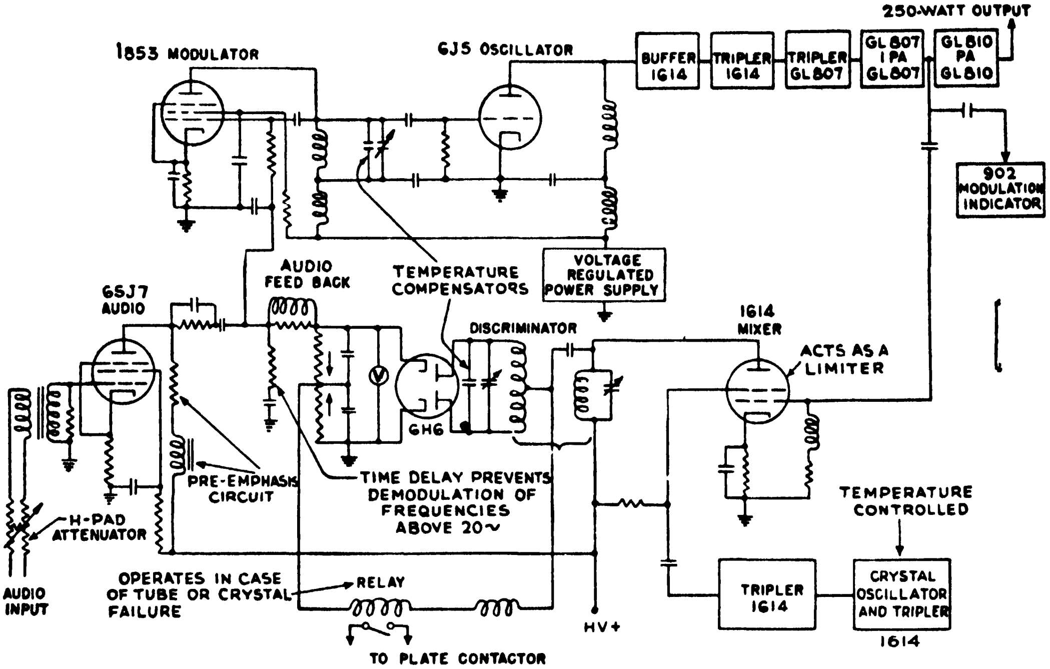

FIG. 7–6. Simplified schematic diagram of f-m broadcast transmitter.

to 3000 kc results. This frequency is fed into a diode rectifier through a discriminator circuit. The rectified voltage, which is used to bias the modulator, varies when the mean oscillator frequency tends to change and consequently serves to maintain the carrier at a constant frequency. A high degree of center frequency control is obtainable by this method.

The manner in which frequency modulation is accomplished by a reactance modulator, Figure 7–7, is explained as follows:

Audio voltages fed into the reactance modulator cause it to act as an inductance or a capacitance, depending upon the way it is connected in the circuit. (In Figure 7–7 it is connected as an inductance.) Since it is connected across the tank circuit of the oscillator, the frequency of the oscillator is varied by the modulating frequencies. The change in inductance is accomplished by making the resistance of R_1 large compared with the reactance of C_1. Consequently, the current through the series circuit R_1C_1 will be practically in phase with the voltage across the tank. The voltage across C_1 will be 90° behind the current because of the well-known property of a condenser to cause the voltage to lag 90° behind the current.

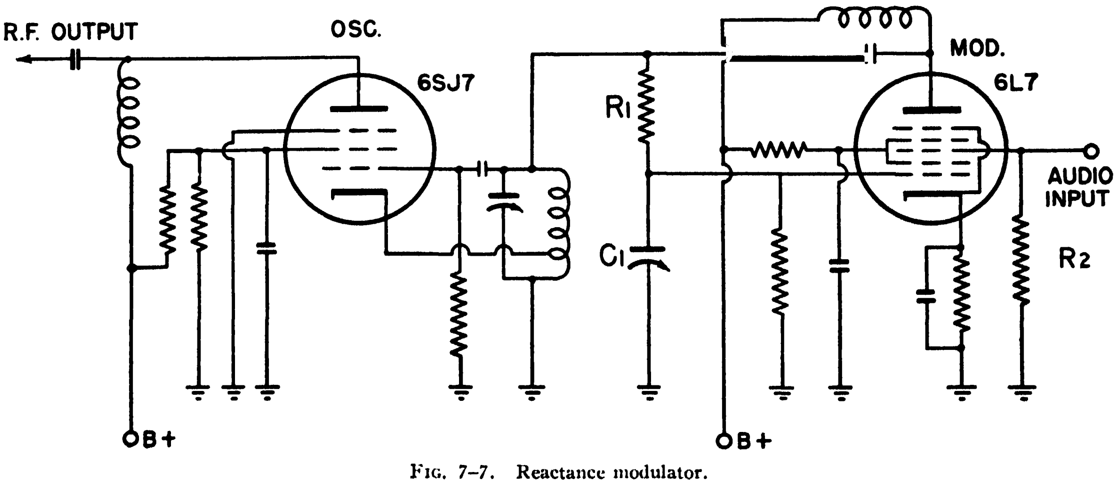

FIG. 7–7. Reactance modulator.

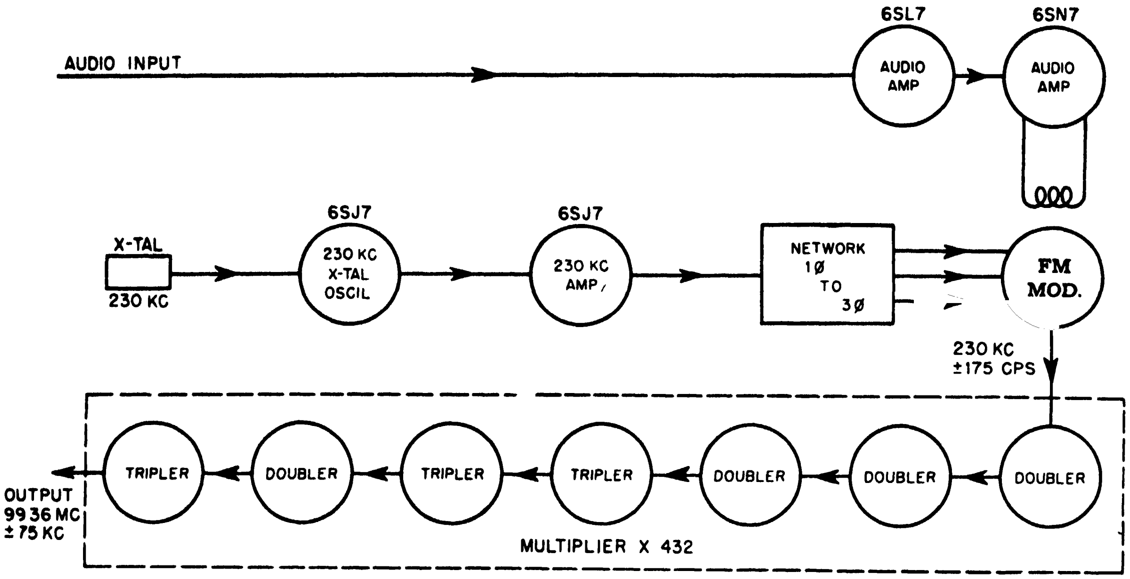

FIG. 7–8. Block diagram of exciter unit employing General Electric Phasitron modulator tube.

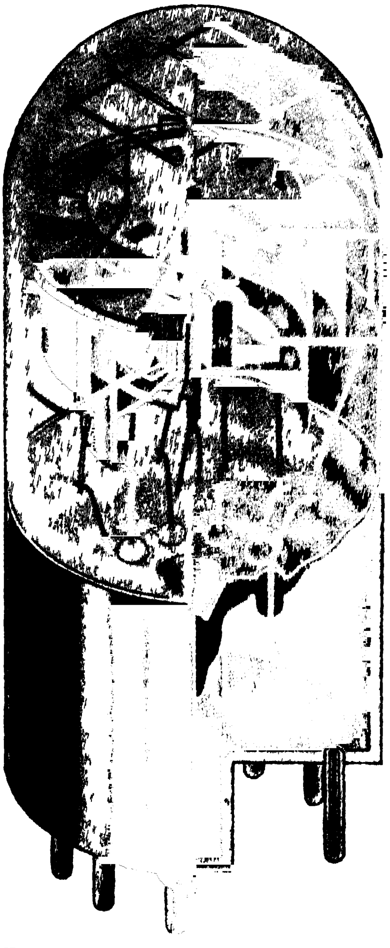

FIG. 7–9. The GL-2H21 Phasitron tube.

The r-f current in the modulator plate circuit will be in phase with the r-f voltage on the grid and, consequently, lags the current through C_1 by 90°. This lagging current passing through the oscillator has the effect of an inductance in the oscillator tank circuit. The variation in inductance is controlled by the amplitude of the lagging current which, in turn, is controlled by the amplification of the modulating frequencies by the modulator tube.

7–8. The General Electric F–M System—The General Electric Company has incorporated in their new F–M transmitters a system of accomplishing frequency modulation utilizing a new type of modulator tube, the type GL–2H21 "Phasitron." The tube was proposed originally by Dr. Robert Adler of Zenith Radio Corporation. In the development of the tube and circuit, basic ideas were contributed by Dr. F. M. Bailey and Mr. H. P. Thomas of General Electric.

The purpose of the modulator tube is to make possible the introduction of comparatively wide phase excursions at audio rates in a crystal-controlled, radio-frequency carrier voltage. The audio response characteristic of the circuit is such that the output of the tube is wide-swing frequency modulation. A schematic block diagram of the circuit employed is shown in Figure 7–8.

The structure of the modulator tube, shown in Figure 7–9, is the basis on which this circuit is built. Figure 7–10 shows an enlarged cutaway view of the tube elements.

Anodes 1 and 2 are maintained at a positive d-c potential and draw electrons from the cathode. By means of the two focus electrodes, these electrons are formed into a tapered, thin-edge disc. This disc, with the cathode for its axis, lies between the

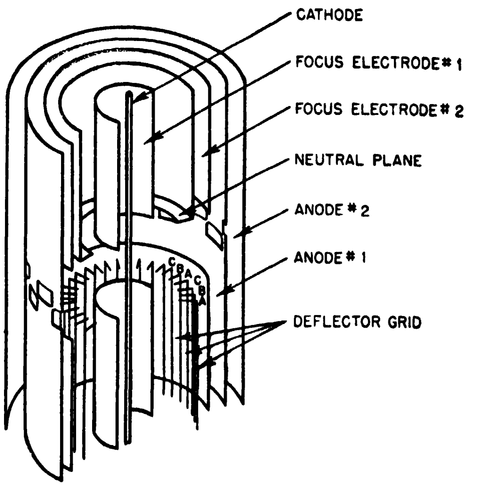

Fig. 7-10. Cut-away view of the GL-2H21 Phasitron.

neutral plane and the deflector grid structure and extends to anode 1.

The deflector grid consists of 36 separate grid wires. These wires are lettered A, B, and C in Figure 7-10. All the A grid wires are connected together, as are all the B and all the C grid wires. Figure 7-11 is a developed view of the grid structure and the neutral plane.

The output of a crystal-controlled oscillator is amplified and fed into a phase-splitting network that converts the single-phase, radio-frequency voltage to a three-phase voltage. This three-phase voltage is applied to the deflector grids as shown in Figure 7-11. Phase A connects to the grid wires marked A, phase B to the B wires, and phase C to the C wires.

Referring to Figure 7-11, the deflecting action on the disc of electrons passing between the deflector grid and the neutral plane is as follows: At instant 1, Figure 7-11, the grid wires A are positive. This results in deflection of the electron disc as shown in Figure 7-11 (instant 1). Shown in perspective, the disc would appear as in Figure 7-12. At instant 2, one-third of a cycle later, grid wires B are positive and wires A and C are negative. The resulting deflection would be as shown in Figure 7-11 (instant 2). The serrated edge of the disc would appear to have moved the space of one grid wire during the time interval between instant 1 and instant 2. With the three-phase voltage applied to the deflector grid, the disc shown in Figure 7-12 would appear to be rotating.

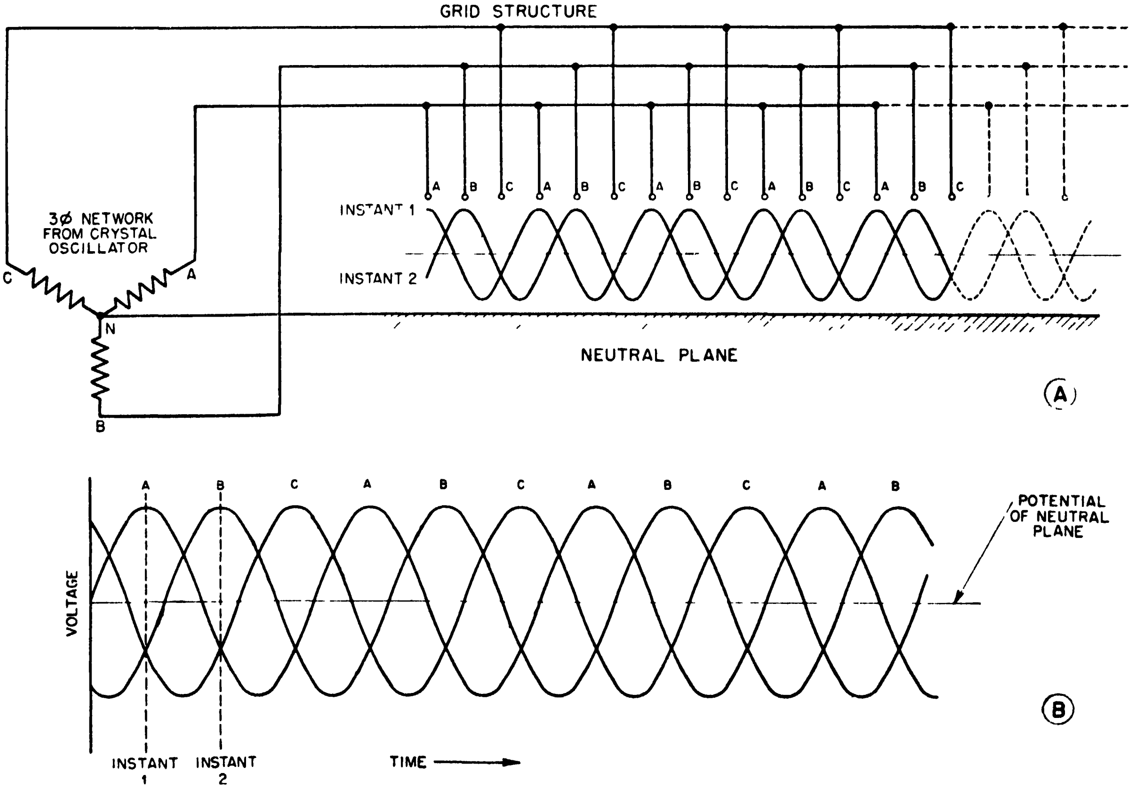

Fig. 7-11. Three-phase voltage applied to deflector grid.

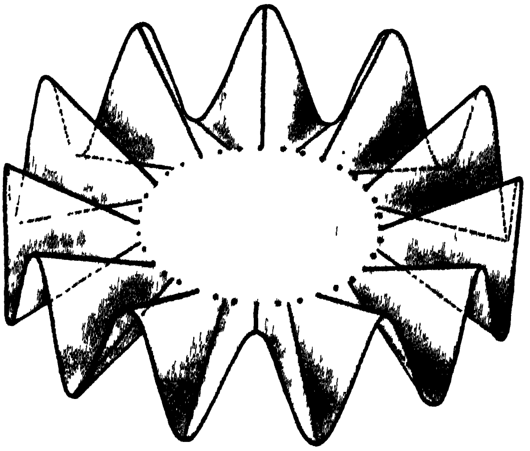

Fig. 7–12. Perspective view of electron disc.

Figure 7–13 shows a developed view of a portion of anode 1. This anode has 24 holes punched in it, 12 above the plane of the electron disc and 12 below. The rotating serrated edge of the electron disc impinges on this series of holes. At an instant when the disc edge is lined up, as shown by the solid line in Figure 7–13, most of the electrons pass on through to anode 2. One-half cycle later the edge of the disc has moved on to the position shown by the dotted line in Figure 7–13. At this instant, few, if any, electrons get through to anode 2. Thus, the current flowing to anode 2 varies sinusoidally at the crystal frequency. Also, it can be seen that any variation in the angular velocity of rotation of the electron disc will result in phase and frequency variation in this output current.

A coil is placed around the tube as shown in Figure 7–14. The magnetic field resulting from a current flowing in this coil is perpendicular to the plane of the electron disc. The electrons traveling radially out from the cathode toward the anodes through this field have a force exerted on them in a direction perpendicular to their path and perpendicular to the direction of the magnetic field. Thus, an angular displacement is introduced in the rotation of the electron disc, causing phase shift in the output current as explained above.

Audio-frequency current flowing in this coil causes audio-frequency angular displacements to be superimposed on the rotation of the electron disc. Thus, audio-frequency phase shifts are obtained in the output (anode 2) current. This current flowing through a load impedance develops a phase-modulated, radio-frequency voltage whose average frequency is that of the crystal.

It can be seen that if a d-c voltage is applied to the coil, the magnetic field set up introduces a fixed angular displacement in the rotation of the electron disc which then continues rotating at the same rate. Therefore, direct crystal-controlled phase modulation is accomplished.

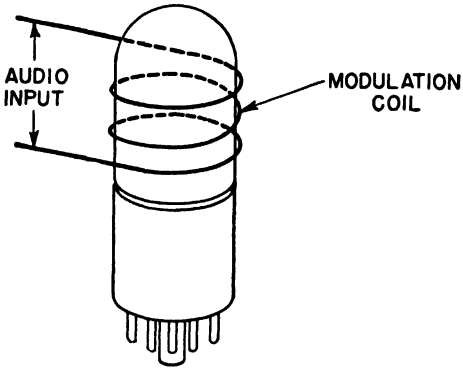

Fig. 7–14. Audio input to the Phasitron tube.

Phase modulation, when performed at a sinusoidal rate, is always accompanied by frequency modulation, which bears the relationship to the phase displacement:

$$Fd = \phi Fa$$

where Fd = maximum frequency deviation in cycles per second

ϕ = maximum phase displacement in radians

Fa = audio-modulation frequency

From this equation it can be seen that, in order to hold the maximum frequency deviation constant,

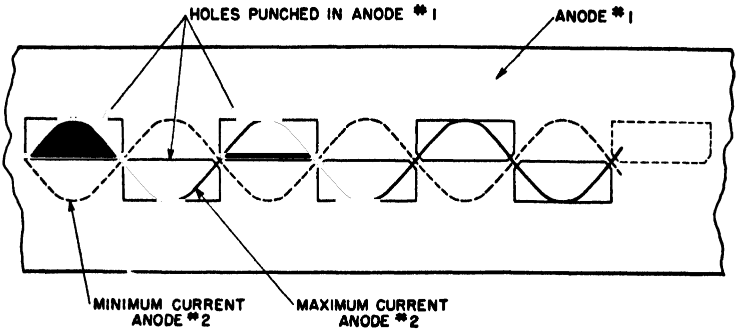

Fig. 7–13 Developed view of anode

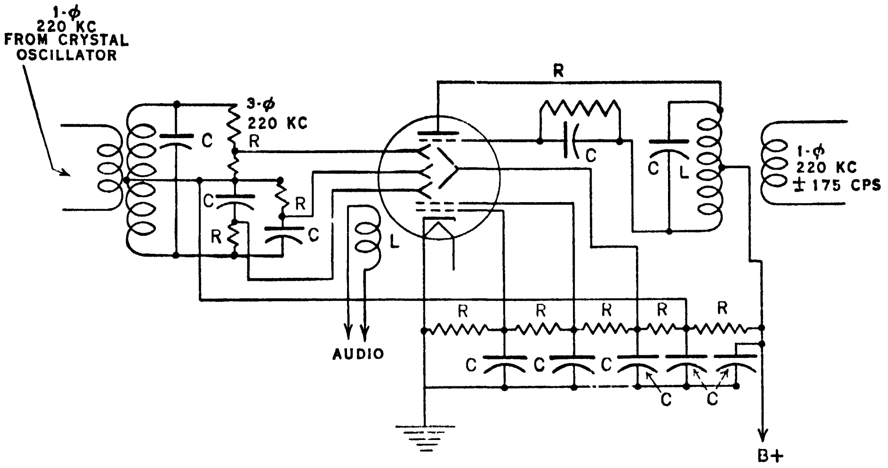

FIG. 7–15. Basic GL-2H21 Phasitron modulator circuit.

the maximum phase displacement must vary inversely as the modulating audio frequency. This can be accomplished if the audio-frequency current in the modulating coil is inversely proportional to the frequency. If the impedance of the coil is purely inductive reactance, the current in the coil will meet the required conditions when a constant audio-frequency voltage is applied; this voltage being independent of frequency. Thus, a driving tube that supplies a constant audio-frequency voltage to the coil will produce frequency modulation directly.

The modulation induced angular phase displacement of the rotating electron disc can be compared with a similar action that is characteristic of a rotating synchronous machine. With no load, the synchronous machine rotor is aligned with the three-phase rotating magnetic field of the stationary armature winding. However, the external application of a load results in a displacement of this alignment in a direction and amount determined by the load. Nevertheless, for any normal load the steady-state rotor speed remains constant.

The modulation coil is driven by a push-pull voltage amplifier that maintains the amplitude of the audio voltage across the coil constant. This means that the current flowing through the coil decreases with increasing audio range. The magnetic field strength, and thus the phase swing of the output current, therefore decreases (6 db per octave) with increasing modulation frequency, effectively giving frequency modulation.

The block diagram of Figure 7–8 shows a total of 12 vacuum tubes (10 r.f. and 2 a.f.) used to arrive at the fully modulated 100-mc carrier frequency. This carrier frequency is crystal-controlled, using a single crystal. This system of modulation permits an extremely wide modulation swing with low distortion and provides excellent signal-to-noise characteristics.

The basic circuit in which the GL–2H21 is used is shown in Figure 7–15. The functions of the circuit are:

1. To supply three-phase, crystal-controlled voltages to the deflection electrodes of the tube.
2. To supply a magnetic field in the direction of the axis of the tube, which varies with time at the audio-frequency rate.
3. To extract the frequency-modulated signal which requires only amplification and frequency multiplication from this stage on.

The GL–21121 tube, when receiving a 220-kc, radio-frequency signal, will deliver to subsequent stages a frequency-modulated signal having a frequency deviation of ±175 cycles from 220 kc. Frequency multiplication of 432 yields an output frequency of 95 mc with a frequency deviation of ± 75 kc. The audio-frequency power required to perform this modulation is approximately 50 milliwatts.

7–9. Westinghouse F–M Frequency Control Circuit—A new method of automatically controlling the carrier frequency of an F–M transmitter has been developed by the Westinghouse Electric Corporation, utilizing a pulse technique. In a recent paper, Mr. J. R. Boykin of Westinghouse explained the operation of the system. This paper includes a discussion of the general problem of automatic frequency control and methods of accomplishing it.

> "Frequency-modulated systems, particularly frequency-modulated broadcast systems, present a number of problems. The system must be capable of modulation, but the center-frequency must be accurately maintained. If the system is what is commonly called direct FM, the modulation is produced by varying the constants of the tank circuit of the primary oscillator at an audible rate. The extent of this frequency shift is approximately one tenth of one per cent, at an audio frequency that may be as high as 15 kilocycles.

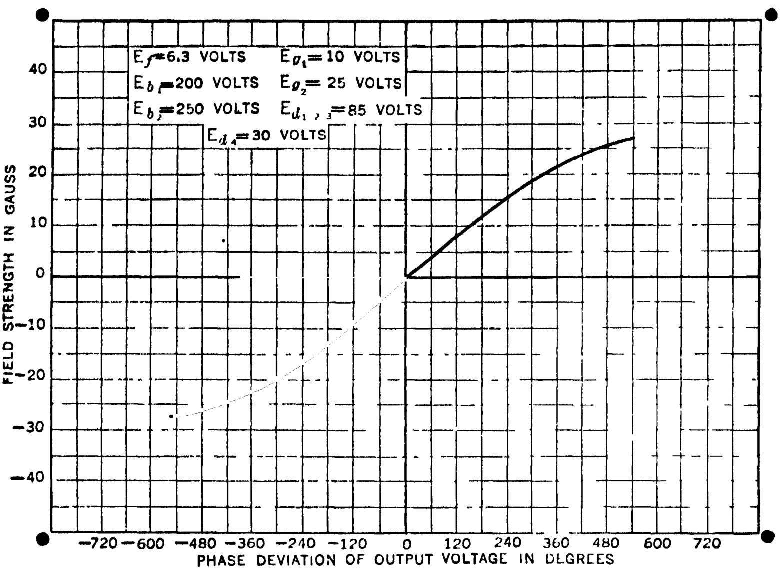

Fig. 7–16. GL-2H21 modulation characteristics.

"To build an oscillator that is capable of being modulated in this manner, it is necessary to keep the tank circuit capacitance low and the inductance high. If a high *C* circuit is used, the oscillator will be so stable that it will be impossible to modulate it to the extent required, particularly at the higher audio frequencies.

"On the other hand, the center-frequency of the system must be maintained within approximately one five-hundredth of one per cent. Using the highest capacitance and the lowest inductance practicable in the tank circuit, and using the best temperature compensation technique in building the oscillator, such stability is still not possible. The fact remains, also, that such an oscillator could not be frequency modulated even if it could be built.

"Since the required stability can not be built into the oscillator, it becomes necessary to use some automatic frequency control system. There have been several such systems devised in the past, one of which utilized an LC discriminator to maintain the center-frequency a fixed number of kilocycles away from a reference frequency which was crystal controlled. Naturally, any drift or mistuning of the discriminator resulted in a corresponding shift of the transmitter center frequency. Another disadvantage was that it was difficult to realize a high control ratio. Control ratios in the order of 15 to 20 were generally used.

"An improved system consists of dividing a sample of the oscillator frequency enough times so that the phase shift resulting from the frequency modulation is approximately one radian or less This frequency, along with two waves in quadrature from a crystal oscillator, are applied to the grids of a pair of mixer tubes. The output of these mixer tubes is the difference between the divided oscillator frequency and the crystal frequency. This output, being two phase, is used to run a synchronous motor which turns the oscillator tuning capacitor in the direction to correct the oscillator frequency. This system presents the usual problems associated with a multiplicity of tuned circuit and moving parts.

"Another system, known as indirect FM, uses a crystal oscillator. The output of this oscillator is phase-modulated and subsequently multiplied enough times to obtain the required frequency excursion. In order to end with the correct carrier frequency, this phase modulation must take place at quite low frequencies, which requires carefully shaped band-pass multipliers. Also,

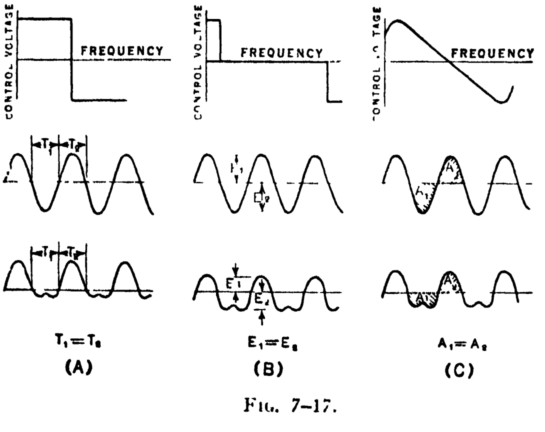

Fig. 7–17.

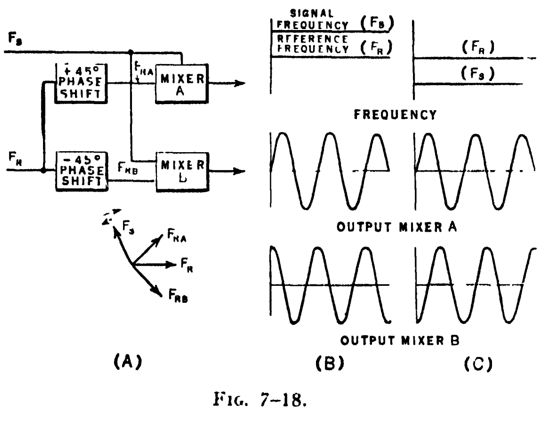

Fig. 7–18.

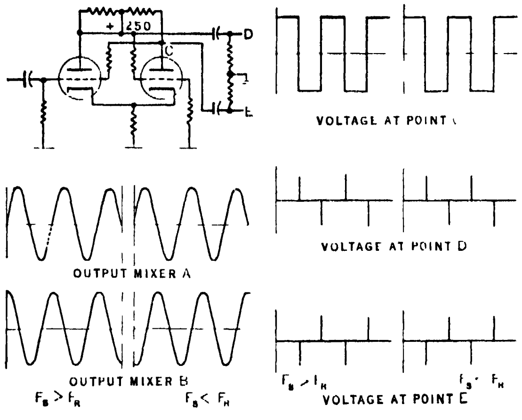

FIG. 7-19.

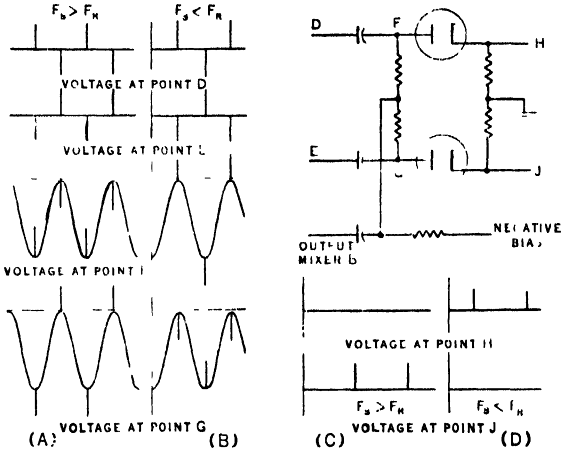

FIG. 7-20.

audio distortion inherent to this system requires that extra precautions be taken to limit it to low values.

"All of the above systems have the property of basing the control on the average frequency. If a plot is made of frequency versus time, and a line is drawn equal to the frequency without modulation, the areas enclosed by the curve on each side of the line will be equal.

"Several systems of frequency control have been suggested which would correct to a different point. One of these would correct to where the total time that the frequency was above the assigned frequency would be equal to the total time that it was below, Figure 7-17a.

"If the modulation was a pure sine wave, such a system would correct to the assigned frequency. With unsymmetrical modulation, however, some of the sidebands would often spill over into the adjacent channel. Another system proposed would adjust the frequency so that the maximum excursion above the assigned frequency was equal to the maximum excursion below the assigned frequency, Figure 7-17b. Such a system would keep the sidebands within the assigned frequency spectrum under steady state conditions, even though the wave form of the modulation was not symmetrical. Under transient conditions, such as are encountered with program material where a non-symmetrical waveform may be quickly followed by another non-symmetrical waveform of opposite polarity, there would be considerable spilling over into the adjacent channels if the correction were slow, or unwanted frequencies introduced if the correction were fast enough to minimize the adjacent channel interference.

"Figure 7-17c shows the correction based on the area enclosed on each side of the assigned frequency. If a crystal oscillator is built to operate on the assigned center-frequency and mixed with the output of the modulated oscillator into a non-linear impedance, a beat note will be produced which has an instantaneous frequency equal to the instantaneous excursion of the modulated oscillator. The total number of cycles of beat note produced while the oscillator is on one side of the assigned frequency will be exactly proportional to the area enclosed by that part of the curve. It follows, therefore, that if the total number of cycles produced while the oscillator is on the high side of the assigned frequency is equal to the total number of cycles produced while the oscillator is low in frequency, then the transmitter is operating at the correct point.

"A new system of frequency control has been developed which takes advantage of this latter fact. Each cycle of beat frequency between the signal frequency and the reference frequency is used to generate a pulse. The pulses are separated into two circuits, one circuit receiving the pulses when the signal frequency is higher than the reference frequency and the other receiving the pulse when the reference frequency is the higher. A pulse counting circuit is so arranged that when a pulse appears on one of these circuits, a definite charge is transferred from a point of fixed potential to a storage capacitor. When a pulse appears on the other circuit, a charge of the same number of coulombs is transferred from the storage capacitor to a point of fixed potential. Since there is no bleeder resistor across the storage capacitor, the charge on the storage capacitor tends to remain constant during any period when there are no pulses. The voltage appearing across the capacitor, which is proportional to the charge stored in it, is used as a control on the reactance tube which controls the frequency of the master oscillator.

"Referring to Figure 7-18a the signal from the modulated oscillator is designated by F_s, and the reference frequency from the crystal oscillator is F_r. This crystal frequency is fed through two 45 degree phase shift networks, each consisting of one resistor and one capacitor of approximately the same number of ohms. One of these networks shifts the phase forward by 45 degrees and the other retards the phase by the same amount. Mixer A and mixer B are used to mix these quadrature voltages with the signal frequency. Figure 7-18b shows the relative output of the two mixers when the frequency of the modulated oscillator is higher than that of the crystal. It will be noticed that the output of mixer B leads the output of mixer A by 90 degrees. In Figure 7-18c the signal frequency is lower than the reference frequency and consequently the output of mixer B lags the output of mixer A.

"The output of mixer A is used to trigger a direct-coupled multivibrator. This multivibrator serves as an electronic switch to make square waves from the sine wave input. Since the input to the multivibrator is much greater than the amount required to trigger it, the time at which the multivibrator turns over will be approximately the time at which the voltage of the output of mixer A passes through zero. At this time, the output of mixer B is at either a positive or negative peak, Figure 7-19.

"The voltage on each of the two multivibrator plates is differentiated by a series capacitor and shunt resistor. The resultant two voltages appear as a series of pulses of opposite polarity. Figures 7-20a and 7-20b show the result when these pulses are superimposed on the output of mixer B. It will be noticed that when the pulses appearing at point D are superimposed on the output of mixer B, the pulses subtract from the sine wave if the signal frequency is higher than the reference frequency, and add to the sine wave if the signal frequency is lower than the reference frequency. In the case of the pulses appearing at point E, the pulses add to the sine wave if the signal frequency is higher and subtract if it is lower. These two signals, appearing at F and G of Figure 7-20c are passed through biased diodes which are used as pulse discriminators. The bias on these diodes is set just above the peak value of the output of mixer B. The result is that when the pulses add to the sine wave, the bias is overcome and the pulse is passed through the diode. When the pulse subtracts from the sine wave, the bias prevents the diodes from conducting and the pulse is not passed. This arrangement serves to separate the pulses onto two circuits. One circuit is energized by one pulse for each cycle of beat when the signal frequency is high, and the other circuit is energized by one pulse for each cycle of beat when the signal frequency is low.

"Figure 7-21 shows two pulse counters arranged in a balanced circuit to control the charge in the storage capacitor C_s. The voltage across the storage capacitor is used to actuate a cathode follower which in turn controls the bias on the modulator tube. Since the modulator tube controls the frequency of the modulated oscillator, the frequency is a direct function of the charge on the storage capacitor C_s. It will be noticed that there is no bleeder resistor across this storage capacitor, hence the system has no natural frequency which the frequency control must overcome. If the average frequency of the modulated oscillator is different from the reference frequency, the charge on the storage capacitor is continually changed in the direction to overcome the difference. When the difference has been overcome, the system becomes balanced, and the only tendency to pull off is due to stray leakages which cause negligible frequency drift.

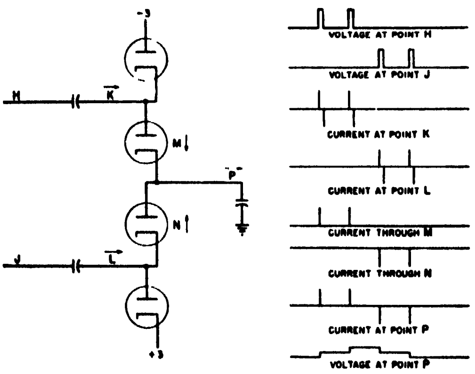

FIG. 7-21.

"The modulated oscillator is operated on one ninth of the assigned frequency of the transmitter. It has been found that simple tuned circuits in the multiplier stages provide adequate selectivity without cutting the side bands when the modulation is applied in this region. When frequencies very much lower are used, special band-pass filters must be employed to provide the bandwidth and selectivity at the same time.

"There are a number of advantages offered by this circuit. Perhaps the most important is the lack of tuned circuits and critical components. The frequency control unit proper contains no tuned circuits, dividers, or locked oscillators. No test instruments are needed to place this equipment in operation. Another important advantage is that tube characteristics are not important. Since each tube in the circuit is driven from grid current to cut-off, merely acting as electronic switches, the actual condition of the tubes becomes relatively unimportant. Long before any tube would become inoperative in the circuit, it would be discarded because of routine tube checks."

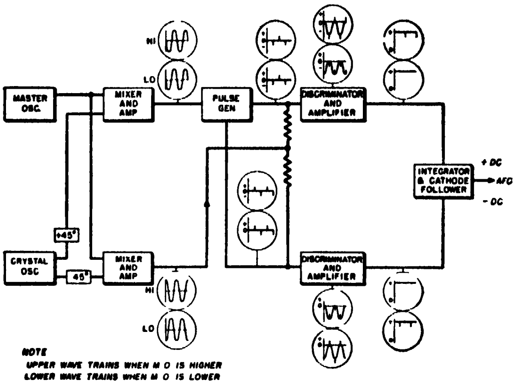
HI
LO
MASTER OSC
MIXER AND AMP
PULSE GEN
DISCRIMINATOR AND AMPLIFIER
INTEGRATOR & CATHODE FOLLOWER
+DC
AFC
-DC
+45°
CRYSTAL OSC
45°
MIXER AND AMP
DISCRIMINATOR AND AMPLIFIER
HI
LO
NOTE
UPPER WAVE TRAINS WHEN M O IS HIGHER
LOWER WAVE TRAINS WHEN M O IS LOWER

FIG. 7-22.

7-10. Pre-emphasis and De-emphasis—Pre-emphasis of the higher audio frequencies of program material at the transmitter, and subsequent de-emphasis at the receiver, is standard practice in F-M and television sound systems. Pre-emphasis is also frequently employed in sound recording, motion picture sound systems, and in some A-M systems (not standard broadcasting).

Pre-emphasis, as applied to F-M systems, consists of increasing the relative amplitude of the higher audio frequencies of the program material. This is usually accomplished through the use of an inductance-resistance network which is connected in the plate circuit of one of the audio amplifier stages of the transmitter. Such an arrangement may be seen in the transmitter of Figure 7-6. De-emphasis in the receiver is accomplished by means of a resistance-capacitance network in the audio amplifier of the correct values to restore the amplitude-frequency characteristics of the program material to its original proportions.

Pre-emphasis is feasible due to the fact that the high-frequency components of music and speech inherently have a relatively low amplitude compared to the frequencies in the middle and low range. This is illustrated in graph form in Figure 7-23, which shows the intensity, or amplitude, levels of orchestral music plotted as a function of frequency. It will be noted that the amplitudes decrease with increasing frequency. The distribution of amplitude as a function of frequency in conversational speech displays similar characteristics.

Because of this characteristic of both speech and music, which constitutes the greater part of broadcast program material, it is possible to accentuate the amplitude of the higher audio frequencies to

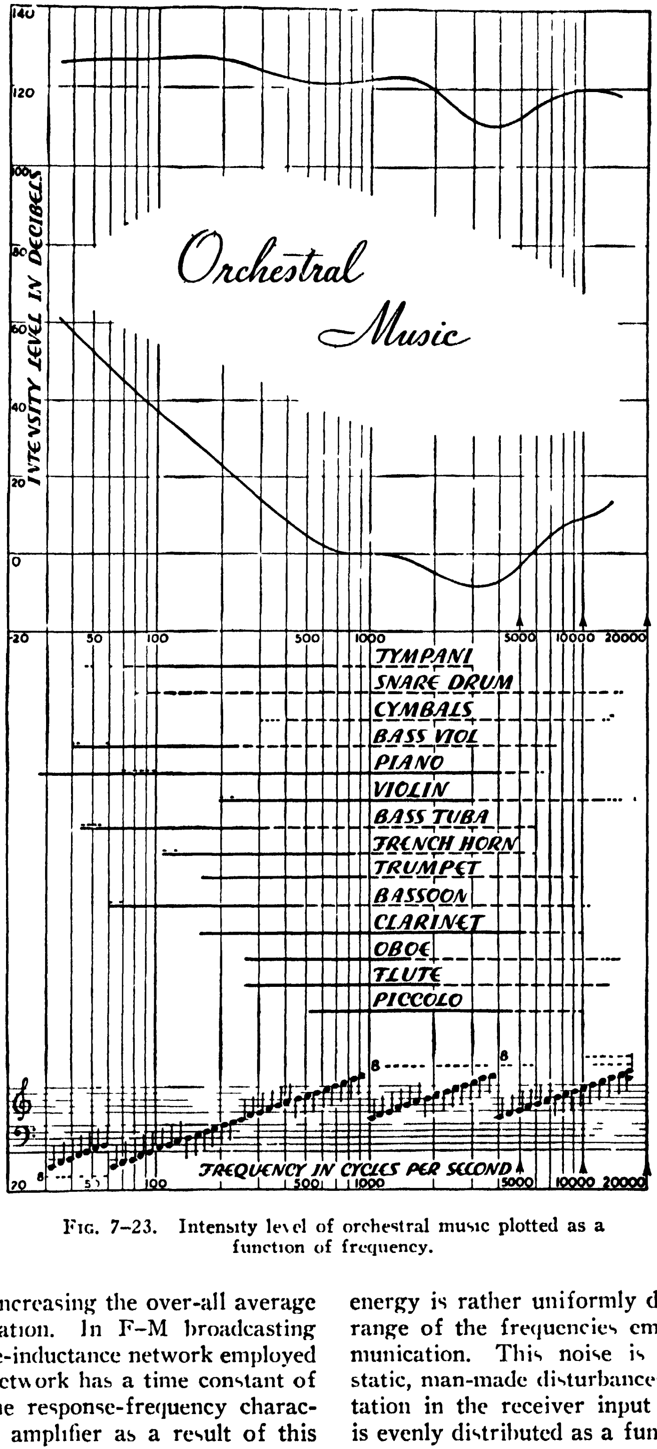

FIG. 7–23. Intensity level of orchestral music plotted as a function of frequency.

some extent without increasing the over-all average percentage of modulation. In F-M broadcasting systems, the resistance-inductance network employed in the pre-emphasis network has a time constant of 75 microseconds. The response-frequency characteristics of the audio amplifier as a result of this pre-emphasis network is shown in Figure 7–24.

Pre-emphasis, with subsequent de-emphasis, results in a substantial improvement in the signal-to-noise ratio of the system. This improved signal-to-noise ratio may be explained as follows: Noise energy is rather uniformly distributed over a large range of the frequencies employed for radio communication. This noise is a combined result of static, man-made disturbances, and the thermal agitation in the receiver input circuit. As the noise is evenly distributed as a function of frequency, the amount of noise intercepted by a receiver will be directly proportional to the bandwidth passed by the receiver. A fundamental requirement for a good signal-to-noise ratio is, therefore, that the response band of the receiver be no greater than is necessary

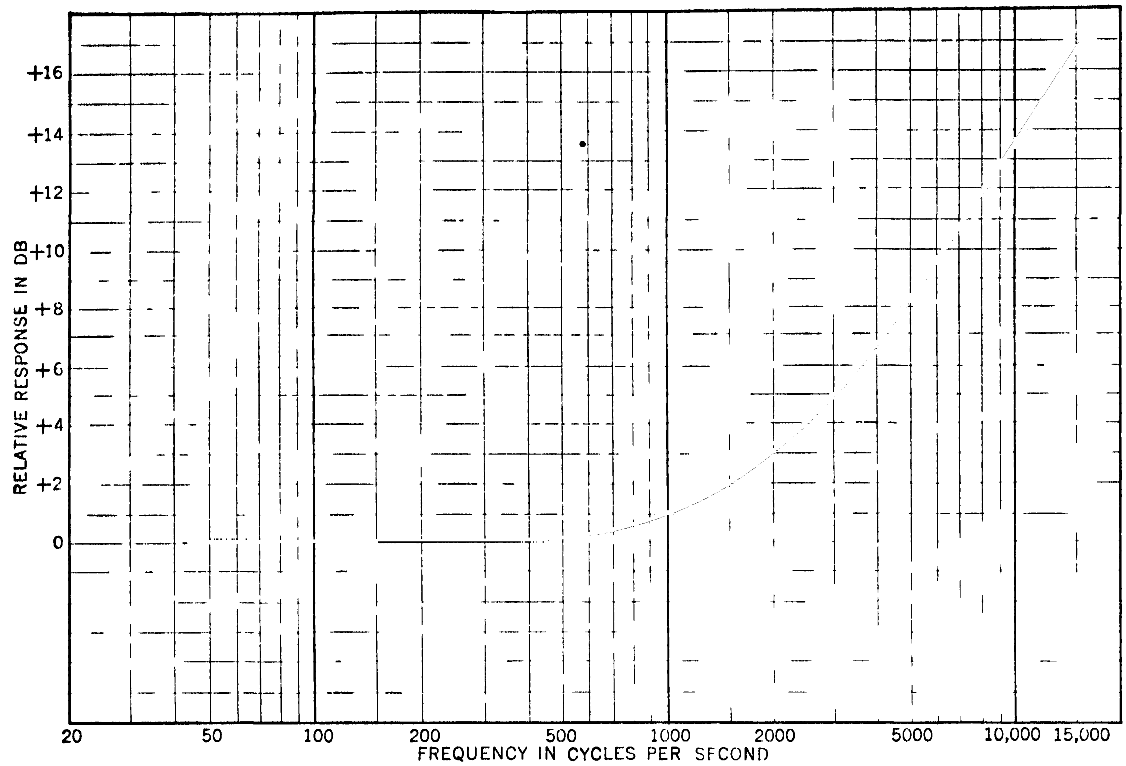

FIG. 7-24 75 microsecond pre-emphasis characteristic employed in f-m broadcasting

to pass the desired signal. Because of the high-fidelity requirements of the F-M broadcast service, F-M broadcast receivers should reproduce uniformly all frequencies up to 15,000 cycles. Were de-emphasis not employed in these receivers, all noise in a 15,000-cycle band would be uniformly amplified.

The use of the de-emphasis circuit in the receiver decreases the response of the receiver to the higher audio frequencies; therefore, it decreases the response to the noise that exists in the corresponding portion of the band. This reduction of noise takes place at the higher audio frequencies where the sound of the noise is particularly annoying.

The response of the receiver to the signal also is reduced at the higher audio frequencies, but inasmuch as the audio components of the transmitted signal are pre-emphasized, the de-emphasis circuit restores the audio frequencies to their original proportions. The response to a pre-emphasized F-M broadcast signal is therefore uniform to the desired 15,000 cycles.

7-11. Measurement of Deviation—In the circuit arrangement of Figure 7-7, it is possible to measure the frequency deviation on both sides of the carrier by making incremental changes in the d-c bias of the grid of the modulator tube. A small bias battery, by means of which the voltage can be increased in steps, should be connected in series with resistance R_2 and the carrier frequency measured precisely each time the grid voltage is increased in a positive direction up to the point where a straight line frequency deviation is no longer obtainable. This process should be followed by applying negative bias to the grid and the frequency deviation again measured, this time in the opposite direction.

From these measurements, the sensitivity of the modulator (frequency change per volt input) is obtained and the limit of linearity determined. In the circuit of Figure 7-7 the condenser C_1 may be used to control the swing. A small value of capacitance permits a larger swing whereas a large value limits the sensitivity. The L/C ratio of the tank circuit also influences the deviation, the higher the ratio (making L larger compared with C), the greater the deviation However, good engineering practice requires that C be as large as practical to minimize frequency drift and hum frequency modulation.

Since the modulator tube is operating as a Class A amplifier, a milliammeter in the plate circuit can be employed to advantage to determine whether the modulation is linear. A change in reading of the meter with modulation denotes nonlinearity in the modulator and likewise in deviation.

7-12. Measurements by the "Bessel Zero" Method—If a frequency-modulation monitor is not available, the frequency deviation and audio-frequency response of a frequency-modulated transmitter may be determined by the "Bessel Zero" method. No knowledge of Bessel functions nor even frequency-modulation theory is necessary, provided that the operator understands what is being done and proceeds with each step carefully. The only equipment required is a low-distortion, variable-frequency audio oscillator and a communication receiver capable of tuning through the required frequency range. The receiver must be equipped with a C-W, or beat-frequency, oscillator. A description of the measurement procedure, given by R. J. Newman,[2] follows:

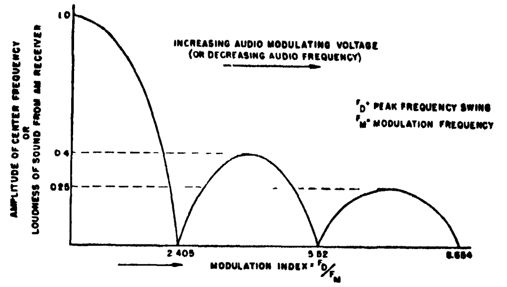

FIG. 7–25. A diagram showing how the "Bessel Zero" points may be found. As level of audio input is increased, the amplitude of the "center frequency" decreases and becomes zero when $F_d/F_m = 2.405$, 5.52, etc.

"*What Is Meant by 'Bessel Zero' Points?* The 'Bessel Zero' method of measurement is based on the fact that the amplitude of the center-frequency component of the energy emitted from an F–M transmitter varies as the amplitude or frequency of the audio-modulating signal is changed. Thus, if the frequency of the modulation is held constant and the amplitude varied, the amount of energy radiated at the center or 'carrier' frequency will vary through wide limits. The reason for this variation is that the modulation energy is distributed, over the frequency spectrum; diversion of energy to 'side current' frequencies takes center-frequency power. These variations in the center-frequency power can be calculated by means of Bessel functions. Ordinarily, they are plotted as a curve of amplitude against 'modulation index,' as shown in Figure 7–25. In order to use this method, it is not necessary for the operator to know how to make these calculations, but simply how to use the resulting curve. The 'modulation index,' which is the abscissa on the curve of Figure 7-25, is the ratio of the frequency swing (usually designated F_d) to the modulating frequency (usually designated F_m). It will be noted that the amplitude becomes zero at several points The first point at which this occurs (when the audio-modulating voltage is increased from zero up) is at the point where the 'modulation index' equals 2.405. If we can identify this point, and if we know the modulating frequency, we can figure out how much 'frequency swing' is occurring, because:

$$\text{Modulation index} = 2.405 = F_d/F_m$$

hence

$$F_d = 2.405 \times F_m$$

"*How 'Bessel Zero' Points Are Found.* The disappearance of the center frequency of the F-M transmitter may be observed with the equipment arranged as shown in Figure 7-26. The procedure is as follows:

"1. Tune the superheterodyne receiver with its C-W oscillator operating) near the unmodulated F-M transmitter frequency, obtaining a low-pitched beat note (about 500 cycles) in the headphones. It is important that the center-frequency beat note heard in the headphones not be confused with that of the side frequencies. The side frequencies increase in intensity and number as the deviation increases. Care in making the adjustments and a little practice will attune the ear to the proper beat note. A low-pass audio filter may be used in the receiver if desired.

"2. Slowly increase the amplitude of the audio-modulating voltage; the transmitter frequency deviation will increase causing the 'modulation index' to increase.

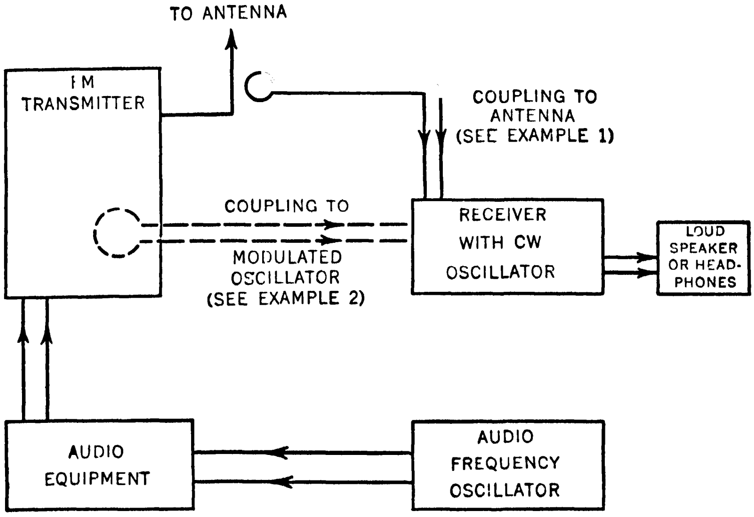
TO ANTENNA
FM TRANSMITTER
COUPLING TO ANTENNA (SEE EXAMPLE 1)
COUPLING TO MODULATED OSCILLATOR (SEE EXAMPLE 2)
RECEIVER WITH CW OSCILLATOR
LOUD SPEAKER OR HEAD-PHONES
AUDIO EQUIPMENT
AUDIO FREQUENCY OSCILLATOR

FIG. 7–26. Arrangement of equipment for measurements by the "Bessel Zero" method.

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[2] R. J. Newman, "FM Audio Measurements with an AM Receiver," *Broadcast News*, No. 39, August 1944. By permission.

Note that:

(*a*) Increasing the modulating index will cause more side frequencies.
(*b*) Energy moves into the 'side current' frequencies and finally the center frequency (audio note in the headphones) decreases to zero.
(*c*) As the modulation index is increased further by a higher modulating level, the carrier (and audio note) will reappear.

"*How This Information Is Used.* Suppose that it is desired to establish the audio level necessary for a given percentage of modulation. The following examples will illustrate how this can be done:

"*Example 1:*

(*a*) Assume that it is desired to establish the audio level for 40 percent modulation (± 30-kc deviation).
(*b*) First it is necessary to find the audio-modulating frequency 'F_m' which will give 40 percent modulation at the first 'Bessel Zero.' This can be obtained from the relation

$$F_m = F_d/2.405 = 30/2.405 = 12.058 \text{ kc}$$

(*c*) Next the audio oscillator is set at 12,058 cycles and the level of the 12,058-cycle frequency increased until the center-frequency component of the emitted r-f energy disappears. At this level the modulation is 40 percent.

"*Example 2:*

(*a*) Assume that it is desired to establish the audio level for 100-percent modulation or ± 75-kc deviation.
(*b*) It is first necessary to find the audio frequency F_m which will give 100-percent modulation at the first Bessel Zero. Using the same relation as before, it is found that:

$$F_m = 75/2.405 = 31.2 \text{ kc or } 31{,}200 \text{ cycles}$$

"This value is impractical since the modulation frequency is too high for the audio system of the transmitter. However, in F-M transmitters employing the reactance-tube type of frequency modulation, both the carrier-frequency deviation and the frequency of the carrier itself are directly proportional to the number of times the frequency of the modulated oscillator is multiplied before reaching the output stage of the transmitter. If the transmitting equipment is tuned so as to triple the modulated oscillator frequency in the modulator or exciter unit, and if this exciter output frequency is again tripled in one of the succeeding r-f amplifier stages, the carrier frequency will be 3 times 3, or 9 times the modulated-oscillator fundamental frequency. The frequency deviation at the oscillator frequency will, therefore, be one-ninth of the 75-kc deviation of the carrier frequency or ± 8.33 kc, and the first 'Bessel Zero' will occur at a modulating frequency of 8.33 divided by 2.405 or 3.46 kc.

"Thus, if the receiver is coupled to the modulated-oscillator stage (instead of the output of the transmitter) and the transmitter is modulated with a 3460-cycle, sine-wave signal, the heterodyne note will disappear when the deviation of the carrier is ± 75 kc. This provides a method of solving Example 2 above, as follows:

"*Example 2* (*cont'd*):

(*c*) The receiver is coupled, by means of a small pick-up coil, to the modulated-oscillator stage.
(*d*) The audio oscillator is set at 3460 cycles and the level of the 3460-cycle frequency increased until the center-frequency component disappears. At this level, the modulation is 100 percent (i.e., deviation is ± 75 kc).

"*Measurements of Audio Response.* The above method may also be used in making audio response measurements by following the same outline to determine the 'Bessel Zero' for each of the several audio frequencies chosen for measurement. It can be seen from the relationship $F_d = 2.405 \times 9 \times F_m$ that the carrier deviation is directly proportional to the audio frequency. Hence, it is possible to determine the audio level required in each case for the first 'Bessel Zero' and then compare both the audio level and the frequency deviation produced for each audio frequency back to a reference point, such as the 100-percent modulation point. The procedure is as follows:

"1. A table is set up, as shown in the table below, listing first the data for the 100-percent modulation condition. This becomes the reference point.

"2. The audio frequencies to be used are listed in the first column, and the levels required for the first 'Bessel Zero' in the second column.

"3. The carrier frequency deviation is determined for each audio frequency from the formula $F_d = 2.405 \times n \times F_m$, where n is the number of times the frequency of the modulated oscillator is multiplied to produce the carrier frequency.

No. 1 Aud. Mod. Freq. cycles	No. 2 Aud. Level Req. for 1st Bessel Zero db	No. 3 $F_d = 2.405 \times 9 \times F_m$ kc	No. 4 $20 \log \frac{F_d}{75 \text{ kc}}$ db	No. 5 Aud. Level (db) − (−2.5 db) db	No 6 Response db
RECEIVER TUNED TO 5 MC					
REF 3460	− 2.5	75	0	0	0
500	−19	10.8	−16.8	−16.5	−0.3
1000	−13	21.6	−10.8	−10.5	−0.3
2000	− 6.5	43.2	− 4.6	− 4.0	−0.6
3000	− 3	64.8	− 1.1	− 0.5	−0.6
5000	+ 1	108	+ 3.2	+ 3.5	−0.3
RECEIVER TUNED TO 15 MC (DEV NOW = 3 × 2.4 × AUD. FREQ.)					
5000	− 8.5	36	− 6.3	− 6.0	0.3
7500	− 4.5	54	− 2.8	− 2.0	−0.8
10000	− 1.0	72	− 2.0	+ 1.5	−0.5
15000	+ 2.0	104	+ 3.2	+ 4.5	−1.3

"4. The logarithmic ratio between the deviation of the particular audio frequency and that of the reference frequency (75 kc) is computed and set down in column 4.

"5. A similar calculation is made (column 5) between the audio level required for the particular audio frequency and that of the reference (3460 cycles per second).

"6. The actual response in decibels is then the difference between columns 4 and 5 taking into consideration, of course, the proper sign.

"The carrier frequency of the transmitter in this example is 45 mc. It should be noted that for the first six frequencies, the receiver was tuned to 5 mc. For the last four measurements, the formula for column 3 becomes $F_d = F_m \times 2.405 \times 3$. This is because for these measurements it was necessary to tune to one-third of the carrier frequency (coupled to the first tripler stage) and continue the measurements there, since otherwise the deviating frequency would exceed 100 kc and the carrier would be overmodulated. The 5000-cycle measurement is repeated for the purpose of checking the accuracy of this shift.

7-13. Frequency-modulation Reception—Reception of frequency-modulated signals compared to the reception of amplitude-modulated signals differs chiefly in the method employed in the demodulation of the signal. The conventional A-M vacuum tube detector is a voltage-operated device, and demodulation of an amplitude modulated carrier by such a detector is possible because the carrier amplitude varies. The amplitude of a frequency-modulated carrier, however, is constant in value and demodulation is not possible unless some arrangement is made whereby the frequency fluctuations are converted into voltage variations. A resonant *LC* circuit is capable of performing this function, the efficiency of conversion being dependent upon the *Q* of the circuit. It would, therefore, seem that any ordinary receiver would be suitable for receiving frequency-modulated signals, since at least one tuned circuit is associated with such a receiver. Such is the case, a regular A-M receiver being capable of providing some intelligibility from F-M transmissions. In adjusting an A-M receiver for the reception of F-M signals, it is necessary to tune a small amount off resonance from the carrier center frequency, otherwise the efficiency of conversion from frequency modulation to amplitude modulation is poor. Such a system of reception is, of course, rather crude and does not take advantage of the noise suppression and high fidelity advantages offered by frequency modulation.

An F-M receiver incorporates the same essentials as a modern A-M superheterodyne receiver up to the second detector tube. Because of the wide band of frequencies involved, a wide-band intermediate frequency amplifier is required; moreover, other tuned circuits must have adequate bandpass capabilities.

7-13a. Limiters—Instead of working directly into a second detector, as does the conventional A-M superheterodyne, the intermediate frequency amplifier of an F-M receiver works into a limiter, which is generally a pentode radio-frequency amplifier with low values of both plate and screen voltages. The effect of this tube operating with low plate and screen voltages, but normal grid bias voltage, is to make it unresponsive to A-M signals, and since, under these conditions of operation, it takes but little signal to saturate the tube (the point on the tube's characteristic curve where a further increase in grid voltage will not increase the plate current), strong signals control the output, and weak signals are suppressed. This action can be compared to a type of automatic volume control. Since both atmospheric and man-made noise have inherent A-M characteristics, they are wiped out by the action of the limiter if it is already saturated by a strong F-M signal. The action of the following second detector, as will be seen, also aids in reducing the response to signals having amplitude variations.

The characteristics of a limiter tube can be best explained by reference to Figure 7-27 where a curve is shown plotting voltage into the limiter versus voltage from the limiter. It will be noted that a certain value of input voltage is required to produce saturation (shown by the dotted line labeled S); i.e., the output voltage does not increase with increased grid excitation from the intermediate frequency amplifier. Beyond the excitation voltage required for saturation, the output from the limiter remains constant until a point (Curve A) is reached where greater values of excitation decrease the output voltage. To prevent this in practice, the tube is biased by means of voltage derived from the output of the IF amplifier by means of an RC network of such values that the limiter output remains substantially contant throughout its normal operating range as shown by Curve B.

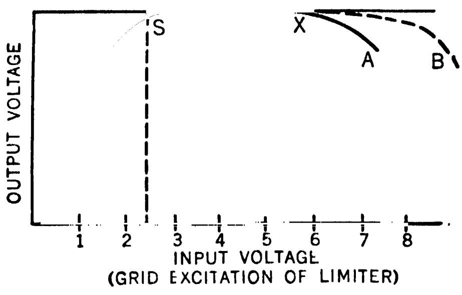

FIG. 7-27. Characteristic of limiter tube.

Limiter circuits have been developed that permit saturated operation with very low values of signal input, thereby effectively increasing the sensitivity of the receiver.

7-13b. Double Limiters—In some F-M receivers two limiters are employed in cascade, thereby providing an even better signal-to-noise ratio. If the incoming signal is too weak to saturate effectively the first limiter, the second limiter prevents the passage of any A-M noise voltages the first limiter has permitted to pass. In practice, it takes a signal of from 0.5 to 2 volts to saturate a limiter.

7-13c. F-M Detector or Discriminator—The detector of F-M signals is quite different in operation than the conventional A-M detector. In one system, a second detector of the "push-pull" type, utilizing a dual diode tube, is energized by the output of the limiter through a discriminator circuit as shown in Figure 7-28. An analysis of this circuit will show that it is similar to the automatic frequency control arrangement used in certain broadcast receivers.

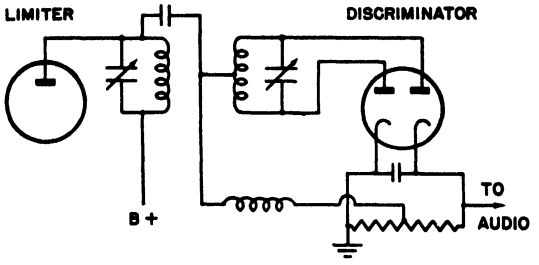

Fig. 7-28. Limiter and discriminator circuits.

A frequency deviation in a given direction causes an increase in the current or voltage output of one, while simultaneously causing a decrease in the output of the other diode. Both diodes, however, respond similarly to changes in amplitude of the applied voltage. Thus, with the output circuits of the two connected in series opposition, amplitude variations can act only to increase or decrease the sensitivity of the combination to frequency modulation and cannot produce output in the absence of frequency deviations. Because of this action, an increase in noise suppression is accomplished, since much of the interference originating from atmospheric disturbances and noise from electrical devices is amplitude modulated. This inherent noise suppressing characteristic of the discriminator operates on noise voltages that have not already been suppressed by the preceding limiter.

It will be noted that the diode cathodes of Figure 7-28 are not connected together, but are tied across opposite ends of a high resistance, one end of which is grounded. The center-tap of the intermediate transformer secondary is connected to the mid-point of the diode load resistance through a radio-frequency choke to provide a direct current path for the rectified current. The r-f choke keeps r-f currents from the audio circuit. The center-tap of the transformer secondary is connected to the high side of the transformer primary through a coupling condenser. Consequently, two paths are provided for the radio-frequency currents to the detector circuit; one by means of capacitive coupling through the coupling condenser, and the other by the inductive coupling of the i-f transformer. The voltage fed through the coupling condenser is in phase with the voltage across the primary of the transformer, while the voltage induced by the inductive coupling is 180° out of phase with the voltage across the primary. Since, at the resonant frequency of the transformer, the current in the secondary will be in phase with the voltage, the windings present only pure resistance; but at frequencies higher and lower than resonance the secondary will show inductive and capacitive reactance, respectively, and the current will lag and lead the voltage.

The rectified voltage developed across the load resistance has the characteristic shown in Figure 7-29, provided all elements of the discriminator circuit are symmetrical. It will be observed that at resonance no voltage is developed across the load resistors, but as the frequency increases above resonance a proportionate negative voltage appears, and as the frequency decreases below resonance a proportionate positive voltage is developed across the load resistors. Thus the audio output amplitude is proportional to the frequency deviation. As already stated, the amplitude of the detected current should be directly proportional to the change in frequency of the transmitted wave and, furthermore, the characteristics of the discriminator and detector network should be linear through the bandpass of the i-f amplifier. To secure these requirements in practice calls for both good design and careful alignment of the discriminator circuit.

As for the audio portion of the receiver, it is essential that it have the necessary audio-frequency characteristics to realize the over-all capabilities of an F-M system.

F-M receivers, in addition to their other technical specifications, are rated in deviation ratio, i.e., one-half the bandwidth divided by the highest frequency of modulation. Receivers designed solely for a communication service do not require the deviation ratio of one employed for high fidelity broadcast reception.

7-13d. Alignment of F-M Receiver—It is essential that the circuits of an F-M receiver be correctly aligned with special attention being given to the discriminator circuit. The amount of frequency swing is limited by the linear range of the slope circuit which converts the frequency modulation into amplitude modulation for detection. Figure 7-29 would reproduce, without distortion, signals within a bandwidth of 40 kc each side of the center frequency. To insure that the discriminator circuit is correctly aligned, as well as to assist with tuning, it is customary to equip commercial receivers with a tuning meter (a microammeter acting as a voltmeter) connected across the load resistors of the diode detector circuit. When the discriminator circuit is properly aligned, the pointer on the tuning meter will show an equal deflection each side of the center frequency. In other words, as the carrier is approached from one side of resonance, the pointer of the meter will move from zero to a maximum on one side and then pass through zero to a maximum in the opposite direction. If the two maximums result in equal deflections from zero, it indicates that the circuits are properly aligned.

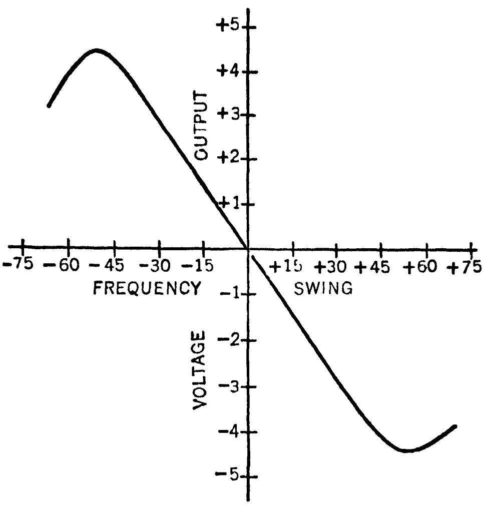

Fig. 7–29. Operating characteristic of discriminator circuit.

When the discriminator is adjusted for linear response, the station is correctly tuned when the pointer of the meter reads zero. This corresponds to the cross-over point of the operating characteristic of the discriminator circuit as shown in Figure 7–29, where zero output voltage corresponds to zero deviation of frequency.

When an A–M test oscillator is used for alignment, it is possible to make fairly good adjustments of the circuit by ear since when the receiver is exactly at resonance (corresponding to the cross-over point) the audio response from the test signal will be almost nil, but as the test oscillator is tuned to either side of resonance, the audio signal will become louder, reaching a maximum at the peaks of the detector characteristic.

7–13e. Ratio Detectors—A new type of F–M detector circuit has been developed by RCA known as the ratio detector. This terminology was derived from the fact that this detector utilizes the ratio of two developed intermediate-frequency voltages whose relative amplitudes are a function of frequency, rather than the difference of those potentials as in the case of the discriminator circuit. The ratio of these voltages remains constant in the presence of amplitude variations, whereas the difference varies if amplitude modulation voltages appear. It is for this reason that it is necessary to use limiters ahead of a discriminator circuit, thus endeavoring to "level off" the applied signals before they are detected. Limiters have the disadvantage that they require large signal amplitude for proper operation which, of course, requires high r-f amplification with attendant tendency toward regeneration and unstability. Moreover, limiters often operate as phase modulators, converting peaks of interference into frequency variations which are consequently reproduced with the program.

A simplified diagram of one type of ratio detector is shown in Figure 7–30. The r-f voltages fed to the diodes in the ratio detector are the same as those in the standard F–M discriminator previously described, and they vary with the frequency swing in exactly the same manner. However, in the ratio detector, the diodes are connected in series so that the d-c (or a-f) voltages which they develop are additive, as contrasted with the standard discriminator circuit in which these voltages are opposed. Moreover, the sum of these voltages ($E_1 + E_2$ as shown in Figure 7–30) is prevented from varying at audio frequencies by the bypass condenser C_4.

Thus it can be seen that, as the sum of the diode voltages E_1 and E_2 is held constant, the ratio of these voltages varies as the ratio of the input voltages to the diodes. Consequently, an audio voltage proportional to the frequency swing appears at the terminals *PB*. In this way, the ratio detector provides an F–M detector equally as good as the standard discriminator and free from the latter's unwanted sensitivity to amplitude modulation whether the amplitude modulation be in the transmitted carrier or originates from interfering sources such as atmospheric noise, automobile ignition, or other sources.

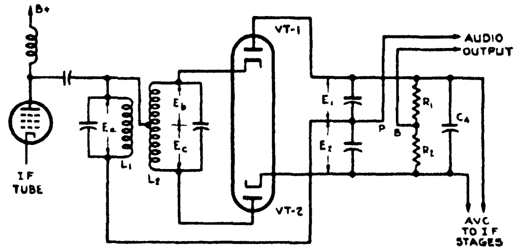

Fig. 7–30. The ratio detector.

While the diodes of the ratio detector are performing their normal function of detecting frequency modulation, they also produce the correct amount of automatic volume control voltage to regulate the amplification of preceding tubes. This "by-product" of the ratio detector can thus prevent overload and "cross-talk," as well as phase modulation by amplitude interference in the preceding tubes and, at the same time, maintain the gain of the receiver at the proper value for any incoming signal.

7–13f. Capture Effect—Capture effect occurs in F–M reception when the stronger signal of two stations on the same frequency completely suppresses the weaker signal. The capture effect will differ in receivers, depending on sensitivity and limiting action and is, of course, dependent upon the relative intensities of the two signals of the same frequency.

7-13g. Common Channel Interference—Co-channel interference will be experienced in two ways. One is the result of two carriers beating with each other as in A-M but, since the two carriers are under modulation, their frequencies will constantly be changing; consequently the beat note will vary in pitch and intensity depending upon the characteristics of the frequency deviation of each station. The amplitude of the beat note is proportional at any instant to the frequency difference and is at a maximum when the two carriers have equal amplitudes. The second source of interference arises when the stronger carrier is unmodulated and the modulation of the weaker station is heard as "cross-talk."

Tests conducted by engineers of the F.C.C. indicated that when the desired station was unmodulated, the average ratio of desired to undesired signal for single limiter receivers is approximately 5 to 1 for elimination of "cross-talk"; however, beat-note interference was still present at this signal ratio. The one receiver tested having two limiters approached a 2 to 1 value for "cross-talk" elimination.

These tests also showed that a ratio of 10 to 1 or higher will probably be required to reduce the beat-note interference between carriers of the same frequency to a tolerable level for co-channel operation. Furthermore, beat-note interference appears to be more or less independent of limiter action. Observations show that receivers with one or two limiters, and receivers without limiters, are about equally susceptible to this type of interference.

Beat-note interference, it is revealed from these tests, depends to a large extent on the accuracy to which the receiver is tuned.

7-13h. Reflections from Aircraft—Interference due to signal reflection from airplanes occurs when a receiver is located at a point of low field intensity. This type of interference begins as a flutter varying in frequency and amplitude as the location of the plane changes with respect to the receiving position.

7-14. F-M Frequency and Modulation Monitors—The rules of the Federal Communications Commission require F-M broadcasting stations to have in operation at the transmitter, an approved frequency monitor independent of the frequency control of the transmitter. The frequency monitor must have a stability and accuracy of at least one-half (± 1000 cycles) of the permitted frequency deviation of the F-M station. Visual indication of the operating frequency must be provided. In addition, the rules require that each F-M broadcast station shall have in operation at the transmitter an approved type of modulation monitor. This monitor may or may not be a part of the frequency monitor.

The general specifications that frequency monitors must meet before receiving type approval of the Commission are as follows:

1. The unit shall have an accuracy of at least ± 1000 cycles under ordinary conditions (temperature, humidity, power supply variations and other conditions which may affect its accuracy) encountered in F-M broadcast stations throughout the United States, for any channel within the F-M broadcast band.
2. The range of the indicating device shall be at least from 2000 cycles below to 2000 cycles above the assigned center frequency.
3. The scale of the indicating device shall be so calibrated as to be accurately read within at least 100 cycles.
4. Means shall be provided for adjustment of the monitor indication to agree with an external standard.
5. The monitor shall be capable of continuous operation and its circuit shall be such as to permit continuous monitoring of the transmitter center frequency.
6. Operation of the monitor shall have no deleterious effect on the operation of the transmitter or the signal emitted therefrom.

Other specifications that the modulation monitor shall meet before it will be approved by the Commission are as follows:

1. A device for setting the transmitter input to the modulation monitor.
2. A modulation peak indicating device that can be set at any predetermined value from 50 to 120 percent modulation (± 75 kc swing is defined as 100-percent modulation) and for either positive or negative swings (i.e., either above or below transmitter center frequency).
3. An indicator using a meter having the characteristics and scale of a standard VU meter. A switch shall be provided so this meter will read either positive or negative swings. The accuracy of reading of percentage of modulation shall be within ± 5 percent at any percentage of modulation up to 100 percent.
4. The frequency characteristic shall not depart from a straight line more than ± ½ db from 50 to 15,000 cycles. Distortion shall be kept to a minimum.
5. The monitor shall not absorb appreciable power from the transmitter.
6. General design, construction and operation shall be in accordance with good engineering practice.

7-15. General Radio F-M Station Monitor—Taking advantage of the option provided in the rules of the Federal Communications Commission, the General Radio Company has combined the frequency and modulation monitor in a single unit. The following description of the General Radio 1170-A F-M Station Monitor was given by C. A. Cady of the General Radio Co. in *The General Radio Experimenter.*[3]

> "When General Radio engineers set out to design the type 1170-A F-M Monitor, their aim was to provide, for the F-M broadcast band and for television audio channels, a monitor that would have the same high quality of performance and simplicity of operation as the monitors for the A-M band that have so long been accepted as standard by the industry.

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[3] *The General Radio Experimenter,* Vol. XXII, No. 5, October 1947.

"The problem of designing an instrument of this caliber was more difficult than that of designing A–M equipment, because of the more stringent requirements set by the F.C.C. on distortion, noise, and audio frequency range. The first step was, therefore, to determine what circuits should be adapted directly from standard A–M practice, and the second to determine what circuits were new and critical.

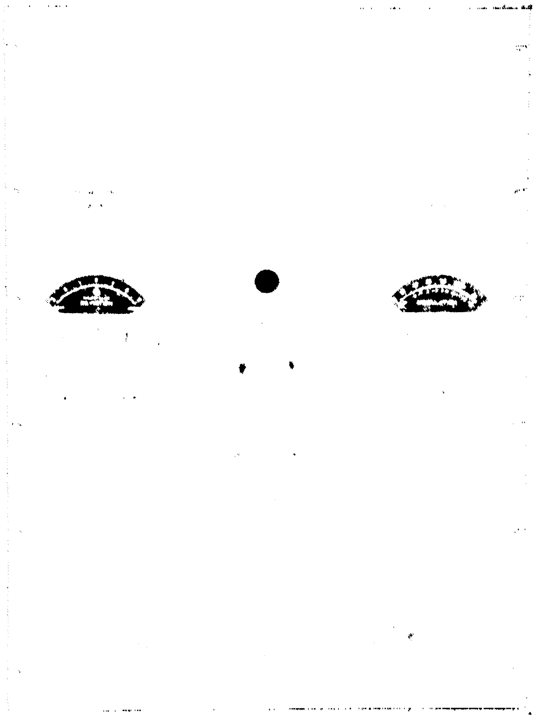

Fig. 7–31. The General Radio type 1170-A f-m monitor.

"To generate the standard frequency, the highly stable crystal oscillator developed for the A–M frequency monitor could be used. Similarly, the modulation indicating circuits could resemble those used in the A–M modulation monitor. The requirements for distortion and noise measurement, however, as well as for adequate stability of center-frequency indication, called for a discriminator better in both linearity and stability than the tuned-circuit type.

"Tuned-circuit discriminators have been used in earlier types of monitors. They are highly sensitive and hence considerably simplify the monitor design. However, the tuned-circuit discriminator is not particularly satisfactory in either linearity or stability. It is basically a nonlinear device. To approximate linearity over a 200-kc range, it must operate at an intermediate frequency of several megacycles. Slight drifts in circuit component values are troublesome so that the center-frequency zero must be continually reset by comparison with a second crystal.

"Pulse counters are inherently linear devices, and a discriminator employing this type of circuit can be made to operate linearly over a wide range with a minimum of critical circuit components and adjustments. The intermediate frequency can be low enough to achieve the stability necessary to eliminate secondary calibration adjustments.

"A characteristic of the counter-type discriminator is its low sensitivity, so that it must operate at a high signal level to give a high signal-to-noise ratio. This need not be a serious limitation, however, for the desired result can be achieved quite simply, and the added circuits are notably free of critical adjustments.

"Consequently, the pulse-counter type of discriminator was selected for use in the General Radio monitor. Using this discriminator, it is possible to obtain an over-all monitoring stability approaching that of the crystal oscillator, or a few parts per million.

"As a result, the original design aim has been completely achieved. The new monitor gives (1) a continuous indication of center frequency without the necessity of frequency calibration checks, (2) an indication of percentage modulation (positive, negative, and full-wave) and a flashing lamp indication of over-modulation, (3) a high-fidelity output for distortion measurements—less than 0.2 percent distortion introduced by monitor, (4) a 600-ohm circuit for audio monitoring. Finally, the monitor is designed for television audio service as well as for F–M broadcasting.

"The functional arrangement of the monitor is shown in Figure 7-32. A harmonic of a crystal oscillator beats with the incoming signal to produce an intermediate frequency of 150 kc. This beat passes through amplifiers and limiters to a counter-type discriminator. The d-c output of the discriminator provides the center-frequency indication, while the a-c output, after suitable filtering, operates the modulation indicators and furnishes a signal for distortion and noise measurements, as well as for audio monitoring.

"The monitor is arranged mechanically so that the various circuits are segregated through the use of individual chassis assemblies. This makes all parts accessible and facilitates maintenance and tube replacements.

"With one exception, vacuum-tube diodes are used throughout the monitor rather than crystal rectifiers. Crystals are not yet commercially available with characteristics as uniform as those of tubes. In particular, crystals exhibit a fluctuation with time in the ratio of front-to-back resistance, which precludes their use in circuits where long-period stability is desired.

"The single crystal rectifier used in the monitor operates the r-f level indicator and the warning circuits, and supplies the bias on a control tube. For these functions, variations in characteristics have little effect.

"Circuit Details. The crystal oscillator circuit is one developed at General Radio specifically for use in frequency monitors. It is highly stable; variations of 4 percent in the circuit capacitance, for instance, change the frequency by less than one part per million. The crystal has a temperature coefficient of less than two parts per million, and its temperature is maintained at 60° within ± 0.15°.

The fundamental frequency of the crystal is between 1.4 and 2.2 mc, and is so chosen that one of its harmonics, when heterodyned with the transmitter channel frequency, will produce a difference frequency of 150 kc.

"The crystal oscillator is followed by an aperiodic buffer amplifier and three multiplier stages.

"The tuned circuits in the multiplier stages have low Q and are operated at a high level to minimize the generation of F–M noise by phase modulation in the successive multiplier stages. A figure of 80 db below 100-percent modulation was chosen as a design objective for residual F–M noise. This is equivalent to a fluctuation of 7.5 cycles at the carrier frequency, or 7.5 parts in 100 million.

"The 150-kc beat between crystal harmonic and transmitter frequency is produced in a pentagrid converter and is amplified by a single output stage.

"For proper operation of the succeeding circuits, it is important that a specified minimum voltage be maintained, at the output of the mixer. An indicating meter is provided to measure this level. Since the voltage at

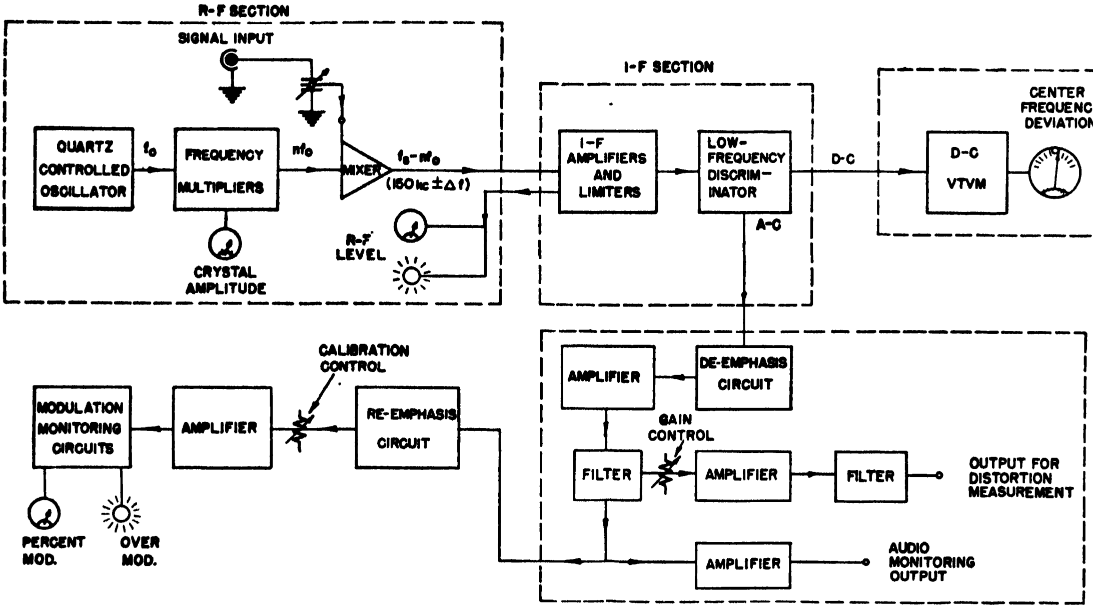

FIG. 7–32. Block diagram of the General Radio 1170-A f-m station monitor.

this point depends on the r-f input, this device is also used as an indicator of r-f input level.

"*Discriminator and I-F Section.* To operate the discriminator it is necessary to generate a square wave of constant amplitude. The 150-kc output from the r-f section passes through a diode clipper, a voltage amplifier, a second clipper, and finally drives two power tubes as limiting amplifiers.

"The amplitude at the output of this amplifier is sufficient to assure a high signal-to-noise ratio and to eliminate all effects of contact potential in the discriminator diodes.

"The voltage level is stabilized by regulating the plate and screen supplies of this final output stage. At this point in the circuit, the signal is a square wave of constant amplitude. The wave shape and the amplitude must be independent of frequency over a range of 150 plus and minus 100 kc in order to provide for wide modulation swings.

"A control tube cuts off the gain of the amplifier tubes until sufficient input voltage has been reached to permit complete saturation of the input clipper stage. This prevents erratic indications on the meter with no input signal.

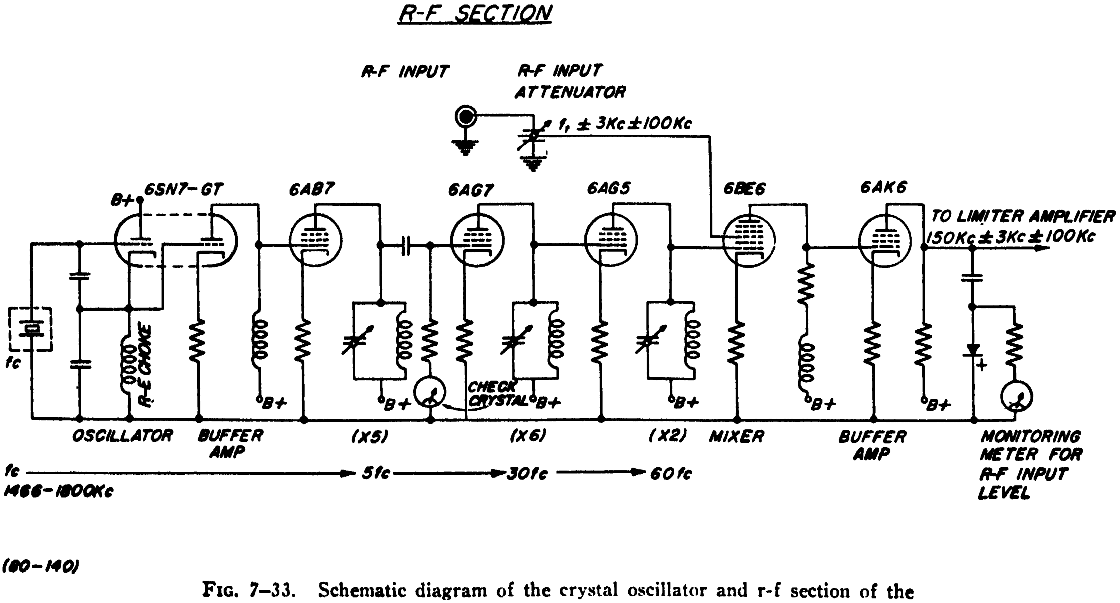

FIG. 7–33. Schematic diagram of the crystal oscillator and r-f section of the General Radio 1170-A monitor.

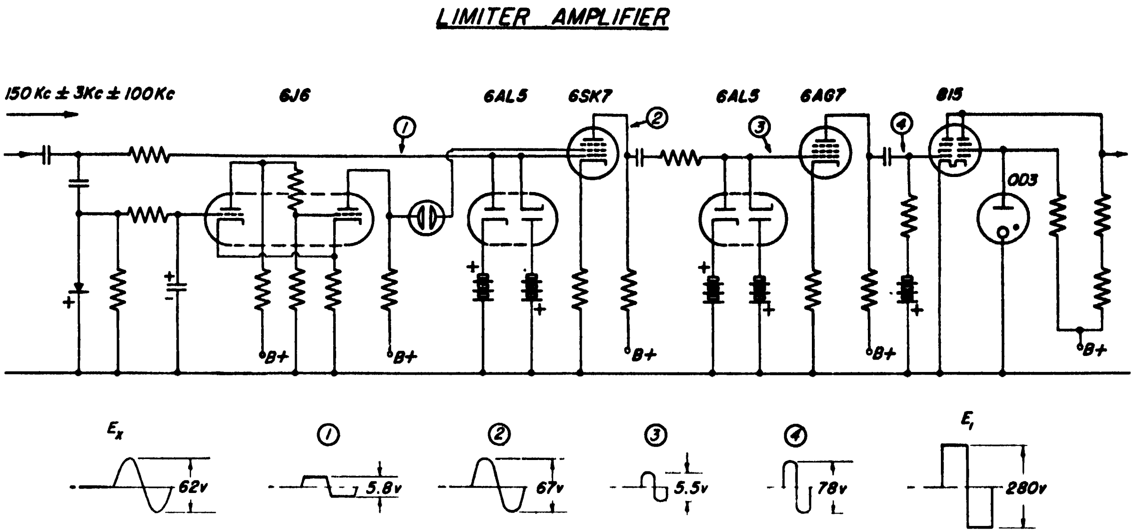

Fig. 7–34. The limiting amplifier section of the General Radio 1170-A monitor.

"The discriminator is shown in elementary form in Figure 7–35. The two diodes are connected in parallel but in opposite sense, so that the condenser is charged through the left-hand diode and discharged through the right-hand one. The time constants of the R–C circuits are made small compared to the time of one-half cycle of the intermediate frequency, so that the condenser is charged to the peak value of the square wave and then completely discharged during alternate half cycles. The output of the discriminator, which appears across the resistor R_2 in series with the right-hand diode, consists of unidirectional pulses of constant shape and amplitude.

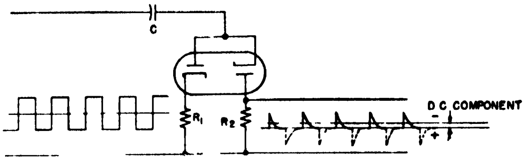

Fig. 7–35. Elementary schematic diagram of the General Radio discriminator. The input waveform is shown at the left, the output waveform at the right.

"When the transmitter is unmodulated, the discriminator output has a d-c component equal to the average value of the voltage across R_2 and a series of a-c components at the pulse repetition frequency and its harmonics. The d-c component varies linearly with the transmitter frequency and consequently can be used to actuate the center-frequency indicator.

"When the transmitter is frequency modulated, the pulses are 'bunched up' or 'spread out' when referred to a time base. The d-c component is not affected by the modulation except to the degree by which the average, or center, frequency changes under modulation.

"Modulation also produces in the discriminator output a component of the modulation frequency, which is

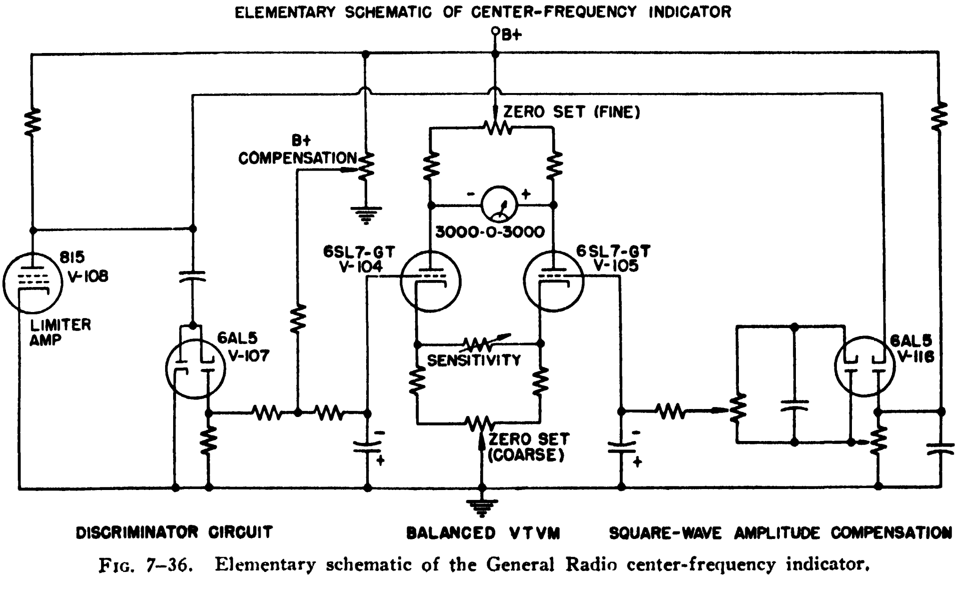

Fig. 7–36. Elementary schematic of the General Radio center-frequency indicator.

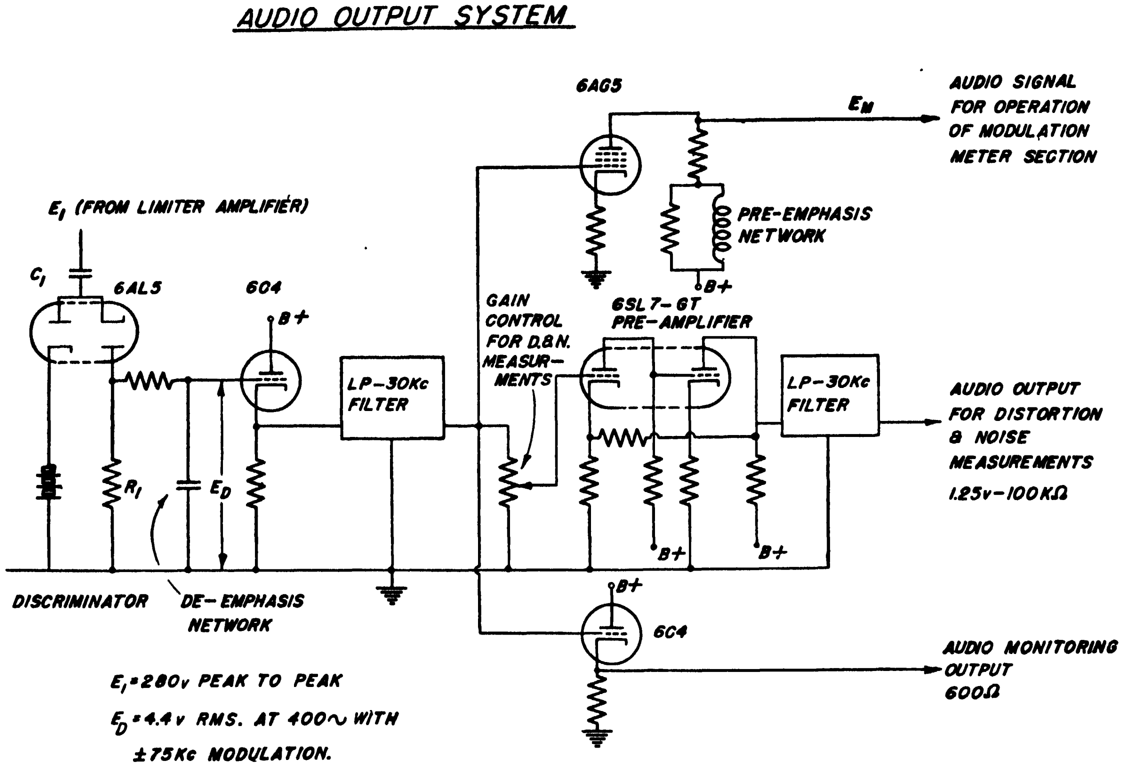
AUDIO OUTPUT SYSTEM
6AG5
E_M
AUDIO SIGNAL FOR OPERATION OF MODULATION METER SECTION
E_I (FROM LIMITER AMPLIFIER)
C_1
6AL5
6C4
B+
PRE-EMPHASIS NETWORK
B+
GAIN CONTROL FOR D.& N. MEASUREMENTS
6SL7-GT PRE-AMPLIFIER
LP-30Kc FILTER
LP-30Kc FILTER
AUDIO OUTPUT FOR DISTORTION & NOISE MEASUREMENTS
1.25v-100KΩ
R_1
E_D
B+
B+
DISCRIMINATOR
DE-EMPHASIS NETWORK
B+
6C4
AUDIO MONITORING OUTPUT 600Ω
E_I=280v PEAK TO PEAK
E_D=4.4v RMS. AT 400~ WITH ±75Kc MODULATION.

FIG. 7-37. The audio output system of the General Radio f-m monitor.

used to operate the modulation indicators and to feed the audio output circuits of the monitor.

"The d-c component of the discriminator output voltage is applied to a vacuum-tube voltmeter, with a bucking voltage that is independent of frequency, to operate a zero-center meter. A center-frequency shift will cause the differential voltage to change in magnitude and sign, and the d-c indicating meter will swing in one direction or the other by an amount proportional to the change in carrier frequency. The bucking voltage is derived from the square wave that drives the discriminator and is proportional only to amplitude. Hence, minor variations in square-wave amplitude will affect the output of both the discriminator and the bucking circuit equally. The use of this amplitude stabilizing circuit eliminates the need for extreme regulation of the plate supply voltages as well as for precise control of all factors influencing the square-wave amplitude over its complete range of carrier swing.

"*Audio-output System.* In order to recover the original modulation signal, the high-frequency components present in the pulse waveform are removed by means of low-pass filters.

"Since the de-emphasis circuit normally employed in the audio-output channels constitutes an *R–C* filter with low-pass characteristics, this network can advantageously be used to couple the discriminator to the audio channels. The high series resistance helps to minimize the reactive loading effects of the external circuits upon the discriminator, and at the same time reduces the high-frequency components of the original pulse.

"The resulting de-emphasized signal passes to a cathode-coupled amplifier and thence to one section of a low-pass filter. This filter section must pass without attenuation all audio frequencies up to 30 kc, the upper limit of audio measurements required by the F.C.C. The second section of the filter is placed directly in the output of an amplifier, whose sole function is to drive the external distortion and noise meter. This filter section eliminates any remaining r-f components including pick-up in the amplifier itself. To insure a minimum of residual distortion, the amplifier is operated at a constant low level. The input gain control can be set to give a constant output for any value of transmitter frequency swing between 6 and 100 kc.

"A second output, intended for local program monitoring, is obtained from a cathode-coupled amplifier with an effective output impedance of 600 ohms, unbalanced.

"*Modulation Metering Section.* A standard pre-emphasis circuit restores the original audio-frequency characteristic for modulation measurements. This apparently roundabout method of producing the modulation signal by first de-emphasizing and then re-emphasizing has one very considerable advantage. As pointed out above, the de-emphasis circuit helps materially to eliminate the radio-frequency components of the pulse waveform. This reduces by the same degree the shielding necessary in the modulation monitoring circuits. The standard pre-emphasis circuit restores the audio-frequency components to a much greater degree than the r-f components.

"An adjustable gain control is provided in the pre-amplifier circuit. This gain control permits the monitor to be calibrated for 100-percent modulation, with any value between the limits of 25 and 75 kc swing.

"The modulation metering circuits and the over-modulation indicator circuit are nearly identical with those used in General Radio A–M monitors. The meter characteristics meet all F.C.C. specifications. An important feature of this monitor, however, is the inclusion of a peak-to-peak, or total swing, indication in addition to the usual positive and negative peak indications.

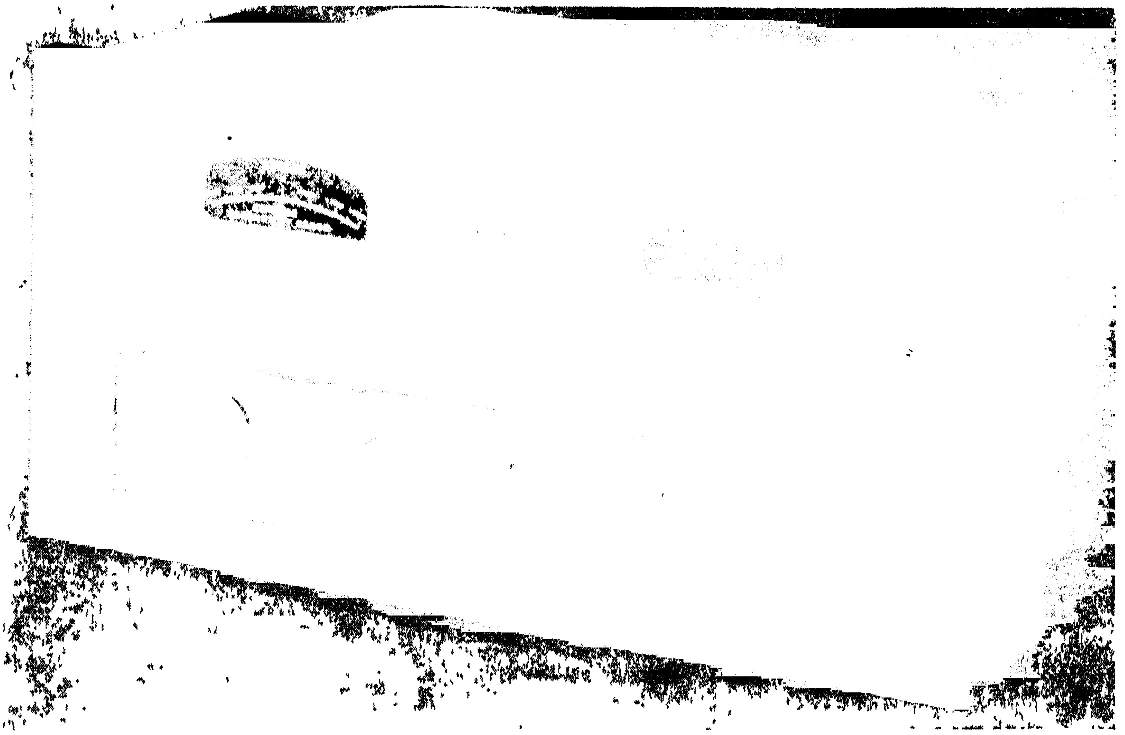

FIG. 7–38. The Western Electric 5A frequency and modulation monitor. The meters provide a continuous indication of the transmitter center-frequency error and the level of transmitter modulation. The light in the center flashes whenever a selected level of modulation is exceeded. High-quality, high-level program monitoring output also permits measurements of transmitter noise and distortion.

Performance Characteristics

"1. *Center-Frequency Indication.* Monitoring practice in the standard A–M broadcast band has accustomed the transmitting engineer to stable center-frequency indicators. A glance at the monitor gives him a frequency indication that can be relied upon without calibration checks.

"Many existing F–M monitors, however, do not have this degree of stability. Consequently, the zero reading must be checked against another crystal standard before a center-frequency reading is taken. It is customary to provide a push button on the panel for this calibration check. Such a procedure is inconvenient and time-consuming and is nearly impossible when remote indicators are used.

"The type 1170–A F–M monitor is designed to give the same degree of stability as is customary in A–M monitors. Its over-all stability is ± 4 parts per million, or about 400 cycles. A zero set is provided, which checks the electrical zero of the meter, but this need be used only once a day.

"When this check is made, the accuracy of indication is bettered by a factor of two and is good to ± 2 parts per million.

"A glance at the meter gives the center frequency of the transmitter, even on a remote meter, and, in addition, a recorder can be operated to give a continuous record of center frequency.

"To prevent erroneous on-frequency indications when the transmitter signal fails or drops below an adequate level, two warnings are provided. The illumination of the center-frequency meter drops nearly to zero, and a pilot lamp on the panel is extinguished.

"2. *Distortion and Noise Measurements.* The F.C.C. has required the use of the standard 75 microsecond de-emphasis network in the measuring instruments. This results in a flat frequency response for the entire system between the transmitter audio input and the measuring device, and so duplicates the conditions actually obtained between studio and home receiver output. Measurements of noise and distortion are, however, referred to a given modulation percentage and frequency. The output voltage available for operation of the distortion and noise meter is thus reduced at the high audio frequencies, and this limits the minimum percentage modulation at which distortion measurements can be made.

"The very low distortion levels that will normally be measured in F–M transmitters impose rigid requirements on all units of the measuring system, and these include (1) the test oscillator, (2) the F–M monitor, and (3) the distortion meter. For this reason it is highly important to keep the residual distortion in any one unit as low as possible, since the minimum indicated level may equal the sum of all components in the system. Cancellation effects may reduce the indicated level below this amount, but, by the same token, readings of the transmitter distortion may be incorrect, should the level be so low as to approach the residual level of the measuring instruments.

"Considerable effort was devoted toward keeping the residual audio distortion in the monitor extremely low and a figure of better than 0.2 percent has been achieved. When the monitor is used in conjunction with a type 1301–A low-distortion oscillator and type 1932–A distortion and noise meter, measurements can be made of F–M transmitter audio modulation distortion values in the order of 0.5 percent rms distortion with a reasonable degree of accuracy.

"Noise measurements in F–M systems will ordinarily be made at levels below −65 db. The residual noise level in both the F–M monitor and the noise meter is therefore of considerable importance. The combination of the type 1170–A F–M monitor with the type 1932–A distortion and noise meter will permit measurements to be made at levels of −75 db with accuracy.

"In addition to its use in the transmitting station, this monitor is suitable for the production testing of F–M transmitters. The combination of the type 1301–A low-distortion oscillator, type 1932–A distortion and noise meter and type 1170–A F–M monitor will permit transmitter type tests to be made as specified in the F.C.C. "Standards of Good Engineering Practice Concerning F–M Broadcast Stations." Because of the wide range of frequencies over which this instrument will operate, and the ease of calibration adjustments, the monitor can easily be used with television aural transmitters. This flexibility of operation permits transmitter design engineers to perform type tests upon F–M transmitters of all types with a minimum of equipment."

7–16. Western Electric 5A Frequency and Modulation Monitor—The Western Electric frequency and modulation monitor for F–M broadcast stations fulfills all the F.C.C. and R.M.A. requirements by a good margin. In addition, the 5A monitor incorporates many features which extend its usefulness. The circuits which contribute to its performance are briefly described in the following paragraphs.

The standard reference crystal oscillator in the Western Electric 5A monitor provides an accurate and low noise level signal at the assigned carrier frequency so that the center-frequency meter can be calibrated and the entire monitor (including the r-f converter) checked for inherent noise level.

It is of interest to note that all crystals used for frequency control, regardless of make or cut, are subject to aging. Investigation has proved that for all quartz crystals frequency drift with aging will amount to several parts per million depending upon the length of service time and the characteristics of the quartz. Considering this aging process, with its attendant changes in frequency, and variations in ambient temperature of as much as ± 60° F, it is probable that the standard reference crystal oscillator will be accurate to ± 200 cycles for several weeks and that it will maintain ± 500 cycle accuracy over the above ambient temperature range for very long periods without reference to a primary frequency standard. Both the standard reference and beating oscillator crystals have extremely low temperature-coefficients, less than one part per million per degree centigrade, and are temperature controlled. The ovens used for temperature control are of a new type and are constructed for fast warm-up and for continuous service. These ovens use two heaters and two thermostats. Both heaters operate until the operating temperature is reached. At this point one heater cuts out and the other maintains the operating temperature. Use of this dual temperature control permits accurate frequency measurements to be taken within ten minutes after the unit is turned on.

7–16a. R–F Converter, Beating Oscillator, I–F Amplifier—The beating oscillator feeds into the r-f converter which mixes the crystal frequency with the transmitter frequency to produce a 10.2 megacycle intermediate frequency. The i-f amplifier is broad band to pass 100-percent modulation (± 75 kc swing) with less than 0.25 percent audio output harmonic distortion, as well as frequency swings of ± 100 kc with less than 0.5-percent distortion. This broad band i-f amplifier further assures that variations of the carrier from its assigned center-frequency will not affect the accuracy of the center-frequency error and modulation percentage measurements.

7–16b. Limiter Circuits—Two stages of limiting provide better than 15 db limiting of amplitude variations, i.e., a 15-db variation in signal input will cause less than a 1-db change in the peak voltage applied to the modulation converter. Of the several limiter circuits, the diode type was chosen for its many advantages—and a further advantage is gained in the limiter circuit by using crystal rectifiers in place of vacuum tubes for diodes. Crystal rectifiers are superior to vacuum tubes for this purpose in that they have long life, no contact potential, and do not require a supply of power for their operation.

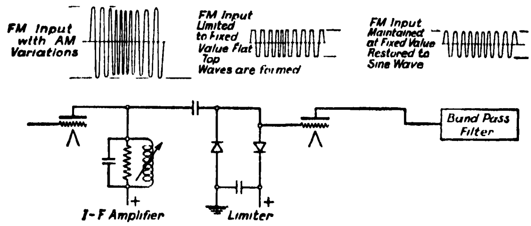
FM Input with AM Variations
FM Input Limited to Fixed Value Flat Top Waves are formed
FM Input Maintained at Fixed Value Restored to Sine Wave
Band Pass Filter
+
+
I-F Amplifier
Limiter

Fig. 7–39. Simplified schematic of Western Electric 5A limiter circuit.

Two crystal diodes connected back-to-back are used in each limiter circuit. They are supplied with a fixed bias voltage and all signal voltages are clipped to a value equal to the fixed bias voltage. Unlike the grid current limiter, this limiter is instantaneous in its response to amplitude variations of the input signal; this keeps the operation of the i-f amplifier tubes in a region below grid current.

Operation below grid current was found to be important because otherwise the operating point and gain of the i-f amplifier changes as the average level of the input signal varies, because of an average change in the rectified bias on the grid of the tube. Furthermore, as the i-f amplifier grid bias varies with changing signal strength, the tube reflects a varying reactance on the tuned circuit of the preceding stage thus causing de-tuning. Such detuning can cause undesirable harmonic distortion.

These undesirable effects do not occur with diode limiters.

7–16c. I–F Bandpass Filter—A bandpass filter is provided at the output of the i-f amplifier and limiters to remove energy at harmonics of the intermediate frequency and other spurious frequencies. The limiter inherently generates harmonic energy at these frequencies which, if permitted to pass would cause an error in the center-frequency indication. The use of the bandpass filter assures that the frequency readings will be direct and influenced only by center-frequency variations.

7–16d. Modulation Converter—The modulation converter is a new circuit for converting frequency modulation into amplitude modulation. It provides an audio signal output by detecting the amplitude modulation by means of series-connected crystal diodes. Here again crystal diodes are used in place of vacuum tubes for the reasons given in the discussion of limiter circuits. Low-temperature coefficient components and construction stabilize the performance characteristics over a wide temperature range.

This circuit has a linear amplitude-frequency response over a range of ± 150 kc and is extremely sensitive to frequency variations (unit current change per kilocycle deviation). This high sensitivity permits operating the center-frequency meter directly from the modulation converter. Direct-current amplifiers with their inherent instability are therefore unnecessary.

7–16e. Percentage Modulation and Program Monitors—The broad-band, i-f amplifier, diode limiters, and modulation converter provide an audio signal output which is a faithful reproduction of the transmitted signal. This audio signal is fed into three separate audio amplifiers.

One amplifier provides a program monitoring output which is so low in inherent distortion and noise that it can be used to check the noise level and harmonic distortion of any F–M broadcast transmitter. The harmonic distortion is less than 0.25 percent. The frequency characteristic of the amplifier with de-emphasis is within ± 0.5 db of the standard 75 microsecond de-emphasis curve. The noise level is at least 75 db below the audio signal resulting from 100-percent modulation. This output can be varied in level as desired from off to + 12 dbm for program monitoring.

A second audio amplifier has a flat frequency response of ± 0.5 db, 30–15,000 cycles. A peak voltmeter, calibrated to show percent modulation, is connected to the amplifier output. The meter scale is calibrated to show important percentage markings. It has damping and response characteristics in accordance with F.C.C. and R.M.A. standards for this service. The scale is indirectly illuminated and color-corrected to minimize eye strain. Connections are available to provide simultaneous meter readings at a remote point.

A third amplifier, similar in characteristics to the second amplifier, operates a thyratron tube and relay which energizes a low voltage filament type lamp. The relay permits the extension of the low voltage lamp circuit to provide peak indicating lamps at any desired remote locations. The relay is fast, positive, and quiet in operation. The gain of this amplifier is adjustable by means of a calibrated gain control so that the lamp or lamps will flash at any selected level of transmitter modulation (40–140 percent).

7–16f. Amplitude Modulation Detector—This circuit, an added feature in the 5A monitor, provides an output which may be read directly on an electronic voltmeter or noise meter. The readings obtained are the A–M noise with reference to 100 percent amplitude modulation in accordance with the F.C.C. requirements.

7–16g. Operation—All controls for the normal operation of the monitor have been located on the front panel. Controls which are used during routine maintenance are located on the chassis and are easily reached from the rear of the unit.

The meter on the left is used to indicate center-frequency errors and the meter on the right is used to show modulation percentages. The modulation meter is also used as a current meter for adjusting the r-f input level. The lamp located between the meters indicates modulation peaks of either positive or negative polarity.

The AUDIO OUTPUT control is used to adjust the audio signal level for program monitoring.

The CENTER FREQUENCY control selects either the transmitter r-f output or the standard reference crystal output. A third position on this switch permits a check of the r-f input level.

CENTER FREQUENCY ADJUST control is used to calibrate the center-frequency error meter with the standard reference crystal oscillator.

MODULATION POLARITY control switches the peak indicator flasher and the modulation percentage meter for indication of either positive or negative peaks.

MODULATION PEAKS control selects the modulation level at which the lamp flashes.

7–16h. General Specifications—The 5A monitor is designed for continuous operation. Normally one watt of r-f power is required; however, power input can vary from $\frac{3}{10}$ to 3 watts, i.e., a 10 to 1 variation without affecting any of the monitor functions or meter readings. Facilities are built into the monitor for indicating and adjusting the r-f input. The monitor occupies 10½ by 19 inches of space on a standard relay rack. The 20C rectifier occupies 7 by 19 inches of space on a standard relay rack. The rectifier may be located remotely if desired. The 20C rectifier is designed for continuous operation from 105–125 volts a-c, 60 cycles. Supply is electronically regulated and output ripple voltage of d-c supply is less than one millivolt.

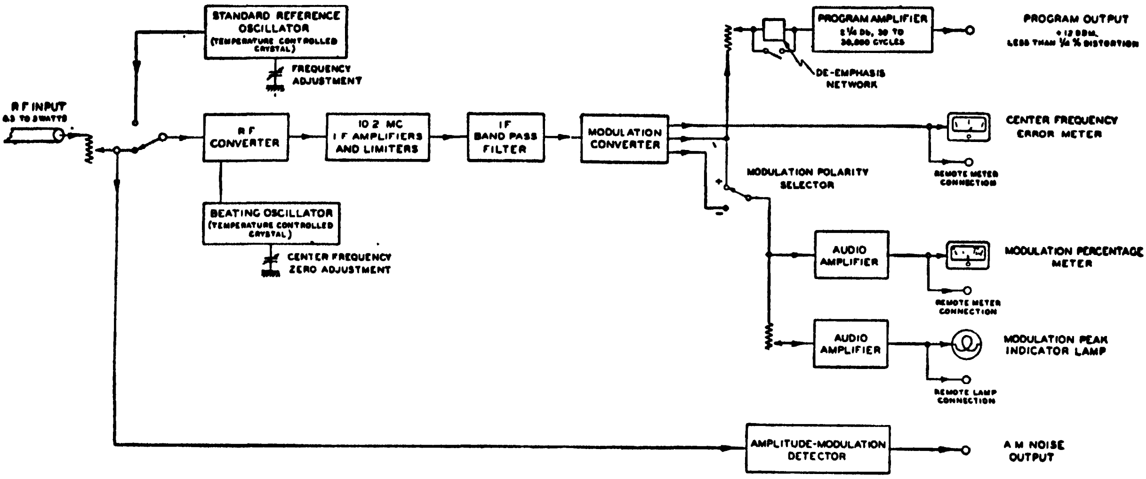
STANDARD REFERENCE OSCILLATOR
(TEMPERATURE CONTROLLED CRYSTAL)
FREQUENCY ADJUSTMENT
R F INPUT
0.3 TO 3 WATTS
R F CONVERTER
10 2 MC
I F AMPLIFIERS AND LIMITERS
I F BAND PASS FILTER
MODULATION CONVERTER
BEATING OSCILLATOR
(TEMPERATURE CONTROLLED CRYSTAL)
CENTER FREQUENCY ZERO ADJUSTMENT
PROGRAM AMPLIFIER
±¼ DB, 30 TO 30,000 CYCLES
DE-EMPHASIS NETWORK
PROGRAM OUTPUT
+12 DBM.
LESS THAN ¼ % DISTORTION
CENTER FREQUENCY ERROR METER
REMOTE METER CONNECTION
MODULATION POLARITY SELECTOR
+
−
AUDIO AMPLIFIER
MODULATION PERCENTAGE METER
REMOTE METER CONNECTION
AUDIO AMPLIFIER
MODULATION PEAK INDICATOR LAMP
REMOTE LAMP CONNECTION
AMPLITUDE-MODULATION DETECTOR
A M NOISE OUTPUT

FIG. 7–40. Block schematic of the Western Electric 5A f-m monitor.

1. *Center-Frequency Monitor*—

ACCURACY: Better than ± 200 cycles. Supplied with a standard reference crystal oscillator which produces a signal at the station's assigned frequency.

FREQUENCY RANGE: Any specified frequency from 88 to 108 mc.

METER RANGE: Plus and minus 3000 cycles. Center-Frequency errors greater than 3000 cycles will show off-scale readings in the correct direction.

2. *Modulation Percentage Monitor*—

ACCURACY: Better than 5% *for all readings.*

MODULATION RANGE CAPABILITY: Up to 3 db above 100 percent (approx. 140 percent) for either negative or positive peaks.

METER RANGE: Scale is calibrated to show important percentage markings, including 100 percent (± 75 kc swing) and 133 percent (± 100 kc swing).

3. *Modulation Peak Indicator*—A lamp mounted on the front panel gives a visual alarm when a selected percentage of modulation is exceeded. Extension lamps may be added as desired for remote control. The point at which the lamp flashes is continuously adjustable, by means of a calibrated front panel control, between 40 and 140 percent modulation. A front panel control permits selection of percentage modulation readings and peak indicator alarm indications on either positive or negative peaks.

4. *Program Monitoring Circuit*—

FREQUENCY RESPONSE: ± 0.25 db, 30 to 30,000 cps without de-emphasis. Over-all frequency response with de-emphasis is within ± 0.5 db of the standard 75 microsecond de-emphasis curve.

AUDIO OUTPUT POWER: Output level up to + 12 dbm can be selected by means of a front panel control. The high level output permits direct switching of the program monitor amplifier from transmitter input to 5A monitor output without the use of intermediate amplifiers.

HARMONIC DISTORTION: Inherent distortion less than one quarter of one percent for all modulation frequencies 30 to 15,000 cps. (Includes all harmonics to 30,000 cycles.)

OUTPUT NOISE: Inherent noise and hum output of the monitor is at least 75 db below the audio output level resulting from 100 percent modulation (± 75 kc swing).

OUTPUT IMPEDANCE: Designed for operation into equipment having a source impedance of 600 ohms or higher.

7-17. Federal Frequency-modulation Broadcast Monitoring Equipment[4]—

"The Federal Communications Commission requires that each broadcast station in this country have a suitable broadcast monitor for monitoring frequency and the various characteristics of the station's modulation. A monitor has two main functions. First, it is required to monitor the transmitter's frequency. The F.C.C. specifiies that this be done to an accuracy of 1000 cycles. Second, it is required to monitor the percentage of modulation on the broadcast transmitter and to indicate by some means when overmodulation occurs. The required accuracy of these two measurements is ± 5 percent. Further, although it is not explicitly stated, the monitor should be capable of measuring the noise and the distortion of the transmitting station. The transmitter is required to have a noise level of at least 65 db below 100-percent modulation and a distortion of less than 1 percent. In order that these be measured, the inherent noise level specified by the F.C.C. for the monitor is 75 db below 100-percent modulation and the inherent distortion 0.25 percent. Some of the other requirements of an F-M broadcast monitor are that the audio amplitude characteristic must follow a standard de-emphasis curve of 75 microseconds to within 0.5 db. Several output levels are required, a high impedance output for noise and distortion measurements and a

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[4] Prepared by M. Silver, Federal Telecommunication Laboratories, Inc. This paper was presented March 3, 1947, at the National Convention of the Institute of Radio Engineers in New York, N. Y.

600/150 ohm output for aural monitoring. Both meters and over-modulation indication should have provision for remote operation. The calibration of the monitor must be self-contained.

"The heart of any F–M monitor equipment, whether its purpose be for modulation monitoring or frequency monitoring, is the discriminator circuit. It was decided to treat the problem of modulation monitoring and frequency monitoring separately so that the most suitable discriminator for each application could be used. It was thought that the higher in frequency the discriminator was operated, the greater its effective bandwidth and the more suitable it would be for modulation monitoring. This meant that we would be obliged to use a tuned discriminator. Further, we could operate such a discriminator directly at carrier frequency. This would eliminate mixing circuits and allow us to take advantage of the maximum bandwidth consistent with simplicity. Several circuits can be used for such a discriminator.

"A conventional Foster-Seeley discriminator, Figure 7–41, might be used, but the circuit is somewhat difficult to operate at frequencies as high as 100 mc. We finally chose the simple off-resonance discriminator. Two versions of this discriminator were developed, a simple inductance-capacitance discriminator and a second version which consisted of two such discriminators operating back to back to take advantage of the cancellation of amplitude modulation thus made possible. Both these arrangements work very well and we were able to measure noise and distortion of very low orders of magnitude. The inherent noise level measured in this discriminator was in the order of -80 db and the inherent distortion in the order of 0.1 percent. This required a Q in the order of 20. This circuit would not be satisfactory for frequency measurements as the sensitivity and direct current stability of the circuit at 100 mc is poor. It was reasoned that the most sensitive circuit possible should be used which dictated a low frequency discriminator. This brought up the possibility of using resistance-capacitance discriminators. The circuit chosen was a simple integrating counter. The details of operation of this circuit will be described later. The counter operated at 150 kc. It is necessary to have a linear discriminator for frequency measurements as the modulation must be integrated and the integration process should not add an appreciable d-c component. This component would appear as an error in frequency measurement during periods of modulation. The counter developed was capable of measuring frequency to an accuracy of 100 cycles, assuming proper calibration of the instrument, under conditions of 100-percent modulation. In view of the linearity requirement of the counter circuit for frequency monitoring, the question of whether the same discriminator could be used for both frequency and modulation monitoring was raised. The linearity of the counter discriminator was far in excess of that required for modulation monitoring and the only significant problem was that of separating the 150-kc keying rate from the 15-kc audio-modulating frequency. Experiments were made to determine the feasibility of filtering the 150 kc and a suitable filter with attenuation of 80 db at 60 kc was devised. Before we proceed, we should consider in some detail the operation of the counter discriminator as finally adopted in the monitor design.

"A square wave is applied to the counter grid circuit, Figure 7–42. This square wave is derived from a series of cascade clippers and limiters. At the time that the negative peak of the grid cycle is reached, the counter tube is completely cut off and the plate voltage raised to a maximum. The condenser is charged through the diode to the peak value of this voltage. During the half cycle this condenser is charged completely. During the second half cycle the grid is made positive and the tube conductive, and the condenser is then discharged through the second diode and counter tube. The aver-

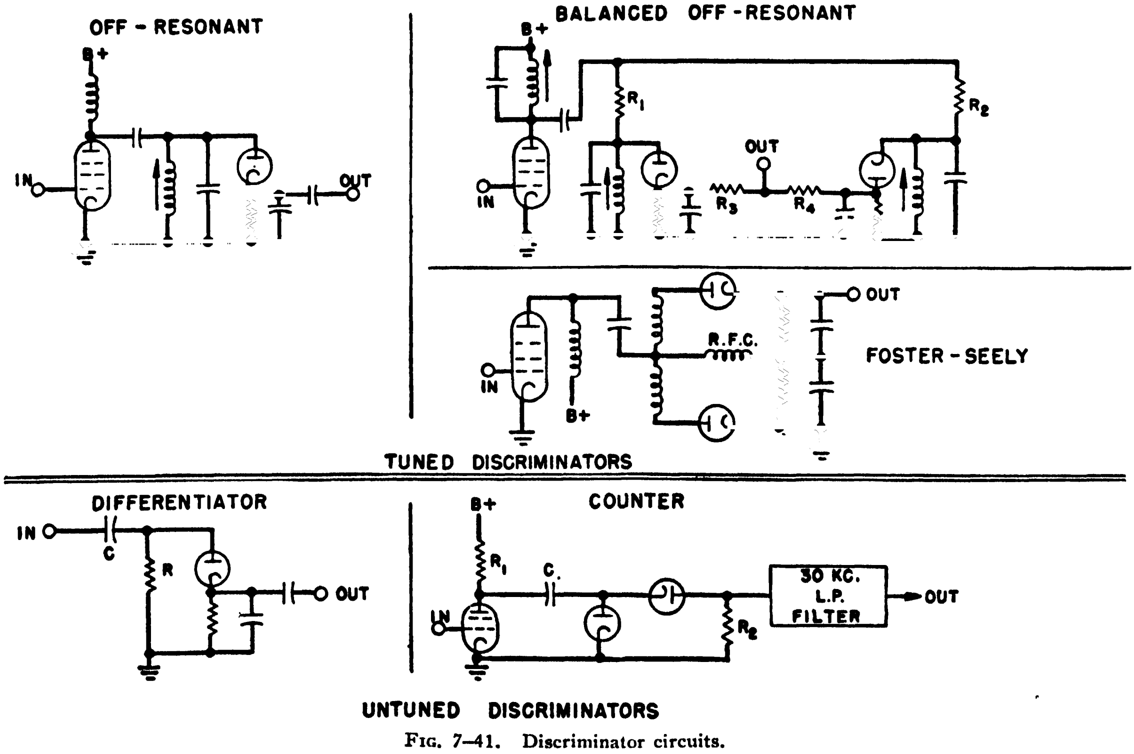

FIG. 7–41. Discriminator circuits.

age value of the current flowing through the meter circuit is a measure of the rate of charge of the condenser and, therefore, a measure of the frequency. In addition, the voltage across the resistor is a measure of frequency and is proportional to the modulation. Therefore, the same discriminator can be used for indicating frequency as well as modulation.

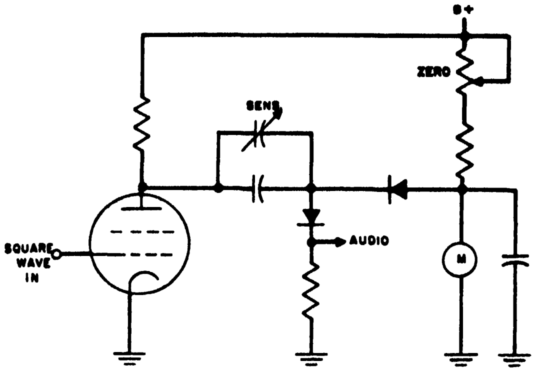

FIG. 7–42. Diagram of counter.

"Two adjustments are provided on the counter, an adjustment for the quiescent balance of the frequency meter and an adjustment of the sensitivity of the counter. The zero potentiometer furnishes a variable bucking voltage applied across the meter M. This adjustment is used for the initial balance of the counter. The charge condenser is made variable to provide an adjustment in sensitivity. The amount of current flowing through the meter M is proportional to the capacity of the charged condenser, and therefore, making that condenser a variable will provide a suitable sensitivity adjustment.

"Now that we have considered some of the requisites of an F–M monitor and the basic circuits chosen, let us look at the block diagram of the complete monitor.

"Basically, the system consists of the cascade limiters previously mentioned, the counter discriminator, the filter network, calibrating circuits, and modulation indicating devices, Figure 7–43. The system operates as follows: a portion of the transmitter's output is mixed with a crystal multiplier output to produce a difference frequency of 150 kc. The crystal oscillator used in this circuit is of the temperature stabilized type and is the standard reference oscillator for frequency measurements. This oscillator is calibrated against broadcast station WWV, with the aid of a secondary standard. The 150-kc output of the mixer is applied through a series of cascade limiter circuits which square and limit the voltage applied to the counter grid. The counter output is applied to a low pass filter circuit and the output of the low pass filter feeds an audio amplifier through a suitable de-emphasis circuit. The audio amplifier has two output terminals, the 600/150-ohm balanced output and a high-impedance output for application to noise and distortion analyzer. Just ahead of the de-emphasis circuit but after the filter, audio voltage is applied through a phase splitter for polarity selection to a vacuum tube voltmeter circuit for percentage modulation measurements and a thyratron flasher circuit for overmodulation indication. In order to calibrate the discriminator, two crystal oscillators are provided: one operating at 150 kc and the second at 147 kc. These two oscillators are used to calibrate the center of the i-f band and the sensitivity of the counter circuit.

"Considering some of the details of the circuits involved, we might first discuss the limiter. This circuit is entirely conventional in all respects, but we might mention that limiters present a problem if all the circuits are of the plate limiting type, because the limiter is then effectively a high gain amplifier and may be subject to oscillation. To avoid too high a gain in the limiter, a clipper circuit was used in the first stage followed by a conventional plate-limited second stage.

"Figure 7–44 is a schematic presentation of the limiter circuits.

"The modulation monitoring portion of the system consists of a vacuum tube voltmeter circuit and an overmodulation indicator.

"Figure 7–45 is a schematic diagram of the modulation indicator circuit. The output of a rectifier circuit

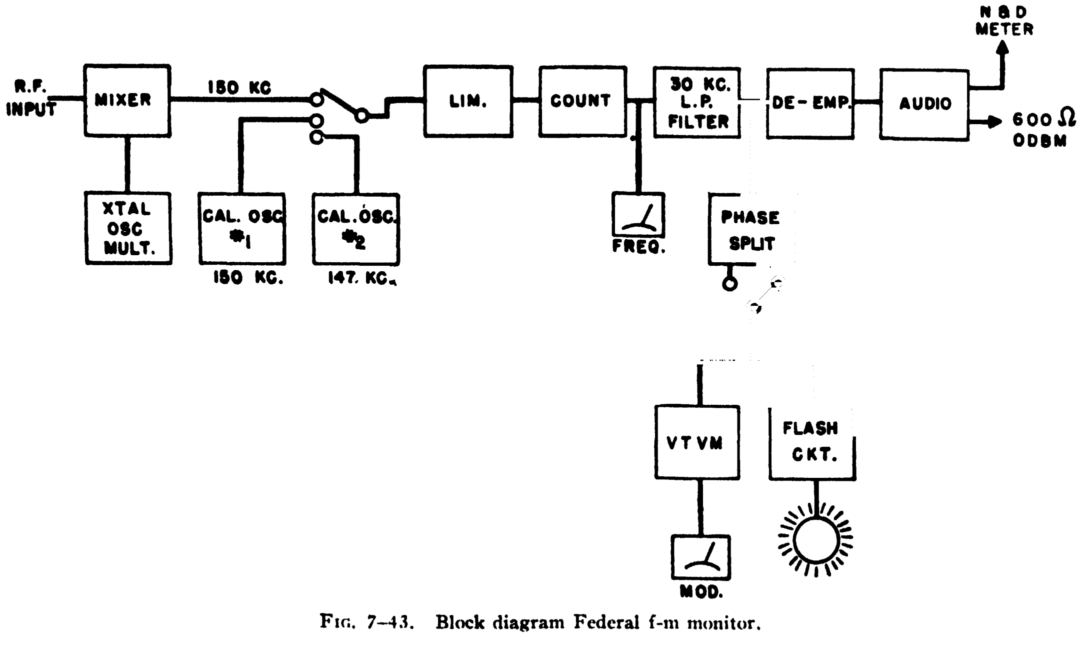

FIG. 7–43. Block diagram Federal f-m monitor.

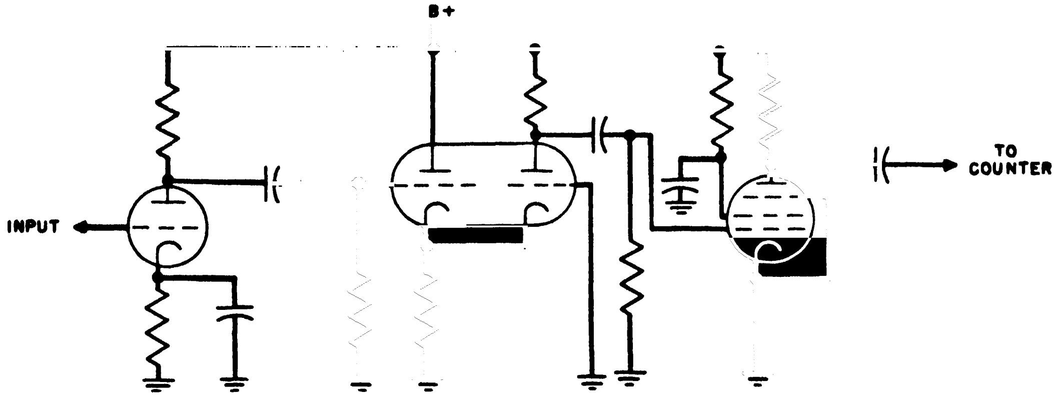

FIG. 7–44. Limiter circuit.

is applied to the grid of a cathode-connected amplifier which serves as a branch of a bridge circuit. A quiescent balance is obtained by adjusting the zero resistor. Under conditions of modulation, the balance is disturbed and current flows through the meter circuit. This current is proportional to the amplitude of modulation.

"The Figure 7–45 rectifier circuit is used to actuate the thyratron flasher circuits. Alternating-current voltage is applied to the plate circuit of the thyratron tube so that it is extinguished, at a 60-cycle rate. The characteristics of the rectifier circuit are such that the charge time is much less than the discharge time so that the peak indication will remain for an appreciable period after the modulation peak has passed. When the voltage on the grid of the thyratron exceeds a gate value determined by the adjustments of the potentiometers, the thyratron tube becomes conductive causing a lamp connected in the plate circuit to glow.

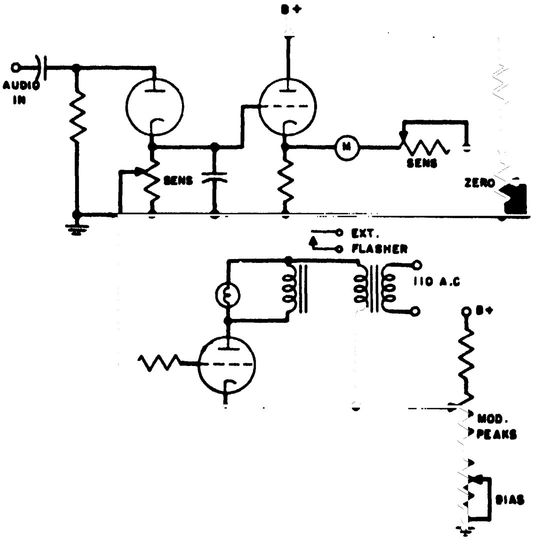

FIG. 7–45. Percent modulation meter and flasher.

"In order to calibrate the modulation indicating circuits, a 60-cycle signal is applied to the input of the rectifier circuit. The amplitude of this a-c voltage is calibrated at the factory and corresponds to 100-percent modulation. Provisions are made for metering the amplitude of this voltage in the field.

"Measuring the characteristics of the monitor presents somewhat of a problem. Since the monitor is essentially a piece of measuring equipment to measure the performance of the F–M transmitter, it would be difficult to build a monitor suitable for monitoring the monitor. We chose, rather than to build a super monitor, to measure the characteristics of the monitor by indirect means. The most difficult characteristics to determine are those of the inherent noise and distortion. Suitable standards are available to measure the accuracy of the frequency calibration, therefore, we will not discuss that problem. Let us first consider the problem of measuring the inherent noise of the monitor. With the output of the monitor connected to a suitable noise and distortion analyzer, we applied to the monitor input, a signal frequency modulated at a 400-cycle rate with a deviation of ± 75 kc. In this case we used an F–M broadcast transmitter as a signal source. By this means we determined a reference level on the noise and distortion analyzer. We can now substitute for the signal source, a crystal oscillator whose plate supply and filament supply are d-c operated. We can then measure the residual noise of the monitor. Fortunately, such a circuit exists within the monitor and we have to merely connect the 150-kc calibration oscillator in place of the transmitter. The noise level measured in this manner is 80 db below that of the reference level, which is better than that required by specification. Determining the inherent distortion is somewhat more complex. We first determine the distortion inherent in the counter circuit and then the distortion inherent in the audio amplifier circuits. The counter distortion was determined by means of a static plot of frequency versus d-c output voltage of the counter, with the aid of an accurate potentiometer. Voltages were determined to four places and the distortion in the counter when measured by this means was in the order of .02 percent. The distortion inherent in the audio amplifier was measured by the use of a noise and distortion analyzer and an audio oscillator whose distortion is 0.1 percent. A distortion of .2 percent was measured at 50 cycles, the frequency at which distortion was maximum. Since the distortion of the discriminator is so much lower than that of the audio amplifier, the inherent distortion of the monitor was determined as .2 percent. This is below the required value.

"Summing up the characteristics of the monitor, inherent noise is 80 db below a reference of 100-percent modulation. The inherent distortion .2 per cent; the error in frequency indication under conditions of 100-percent modulation, ± 100 cycles, assuming proper calibration of the reference crystal oscillator; the error in modulation percentage and overmodulation indication is ± 5 percent.

"In conclusion, we might mention that a plate power supply with a ripple level of less than two millivolts was required. A hard tube regulator circuit with additional feedback was used. It was also necessary to operate the filament circuits with direct current to reduce the noise level to the low values measured. The d-c filament supply is obtained by means of selenium rectifiers. The complete equipment, including the power supply, is contained in two chassis. Figure 7-46 is a front panel view of the F-M broadcast monitor."

7-18. General Electric F-M Station Monitor—There is given below a description of the General Electric BM-1-A F-M station monitor based on a paper delivered at the Broadcast Engineering Conference by H. R. Summerhayes, Jr. The text of Mr. Summerhayes' paper has been modified slightly to adapt it to the text of this volume.

"F-M broadcast stations are required by the Federal Communications Commission to have in operation approved monitors for indicating frequency, percentage modulation, and modulation peaks. The General Electric Company originated the idea of a station monitor in which these functions were combined, and developed such an instrument in 1940 wherein four important characteristics of a frequency-modulated broadcast signal were continuously monitored. The instrument measured and continuously indicated the mean frequency and the percentage modulation of the radiated signal. It also provided a modulation peak indicator with a warning flasher to show when modulation peaks exceeded some preset value, and it provided an audio output for use with an external amplifier for aural monitoring of the program.

"When the frequency allocation for F-M broadcast stations was raised from the 42-50 mc band to the 88-108 mc band, it became necessary to provide an instrument to accommodate the new frequency range. The performance of the new instrument was also extended to meet the extremely low distortion and noise level required for making the transmitter proof of performance tests specified by the Federal Communications Commission. In addition, a balanced audio output was desired, as was also a means for indicating the radio-frequency input level to the monitor.

"*Development Problems.* Since the original instrument performed the basic monitoring functions simply and satisfactorily, there were obvious advantages in using the same general circuit in the new one. The old circuit was essentially a superheterodyne receiver with additional measuring and indicator circuits. The local oscillator signal was derived from a crystal controlled oscillator with appropriate frequency multiplier stages. Some limiting action was achieved by introducing the transmitter signal into the mixer at a saturation level. There was a single, very broad-band i-f transformer at 5.4 mc in the mixer plate circuit. The discriminator amplifier was operated Class A to avoid the spurious center-frequency change encountered when limiting is

FIG. 7-46. Federal f-m broadcast monitor.

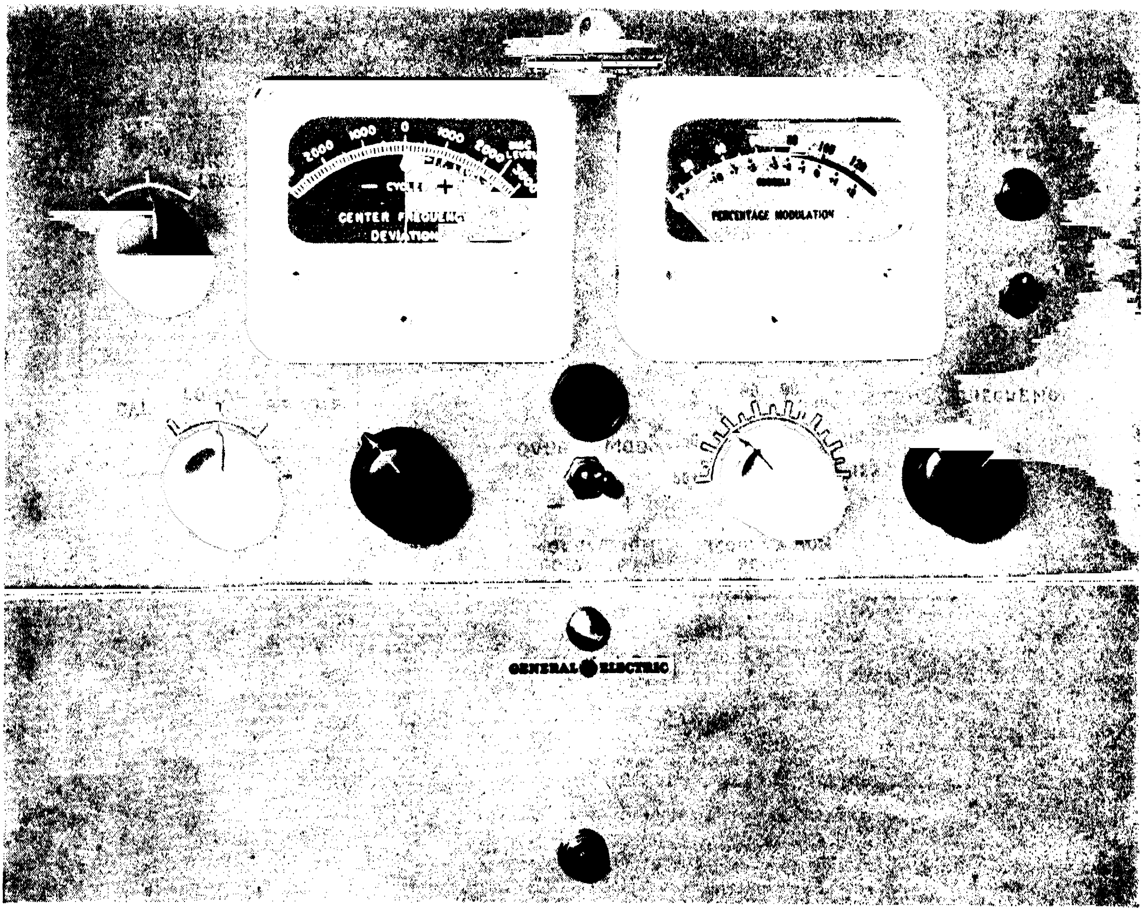

FIG. 7–47. General Electric model BM-1-A f-m station monitor.

used at the discriminator amplifier grid. The discriminator itself was a modification of the commonly used double-tuned circuit with two diodes, each one connected to rectify the sum of the primary voltage and one-half the secondary voltage. However, the structure of the more conventional discriminator was modified in such a way as to facilitate monitoring the frequency directly without d-c amplification.[5] Other features such as a specially wound inductance coil and a crystal-controlled calibration oscillator were included to meet the stringent requirement on discriminator accuracy.

"When the present instrument was developed, each of the new requirements was considered to see whether or not it could be met by improvements on the original design. The increase in operating frequency to 88–108 mc called for redesign of the frequency multiplier and mixer sections with miniature tubes indicated for the high-frequency stages. This requirement, as well as others including measurement of r-f level and change in the audio system, could still be met by the basic design of the original instrument.

"*Noise Level and Harmonic Distortion.* The most difficult requirement was the one on audio distortion and noise level. As is usual in a measuring device, the performance must be considerably better than the devices it is used to measure. It is desired to be able to indicate transmitter noise as low as 70 db below 100-percent modulation and transmitter harmonic distortion less than 0.5 percent. These considerations led to specifying an inherent noise level for the monitor not to exceed −75 db and a total harmonic distortion not to exceed 0.25 percent.

"The noise specification can be met with the tuned discriminator as far as audio noise due to power supply ripple is concerned. It is more difficult to keep to a low level the spurious beat notes arising from harmonics of the crystal-controlled oscillator mixing with the intermediate frequency or its harmonics. For ordinary noise considerations, it is sufficient to avoid the more obvious combinations of frequency, but, in this case, where the noise level should be below −75 db, it was found that beat notes arising from such combinations as the fourth harmonic of the crystal-controlled oscillator frequency and the third harmonic of the intermediate frequency gave interference trouble. These difficulties are inherent in a superheterodyne circuit using a crystal-controlled oscillator and a frequency multiplier and can only be obviated by careful choice of oscillator frequency and multiplication factor.

"The specification of 0.25 percent on allowable total harmonic distortion includes distortion due to nonlinearity of the discriminator detection characteristic as well as distortion produced in the audio amplifier. It was decided that 0.15 percent for the discriminator and 0.1 percent for the audio amplifier would be satisfactory.

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[5] U. S. Patent No. 2,309,481.

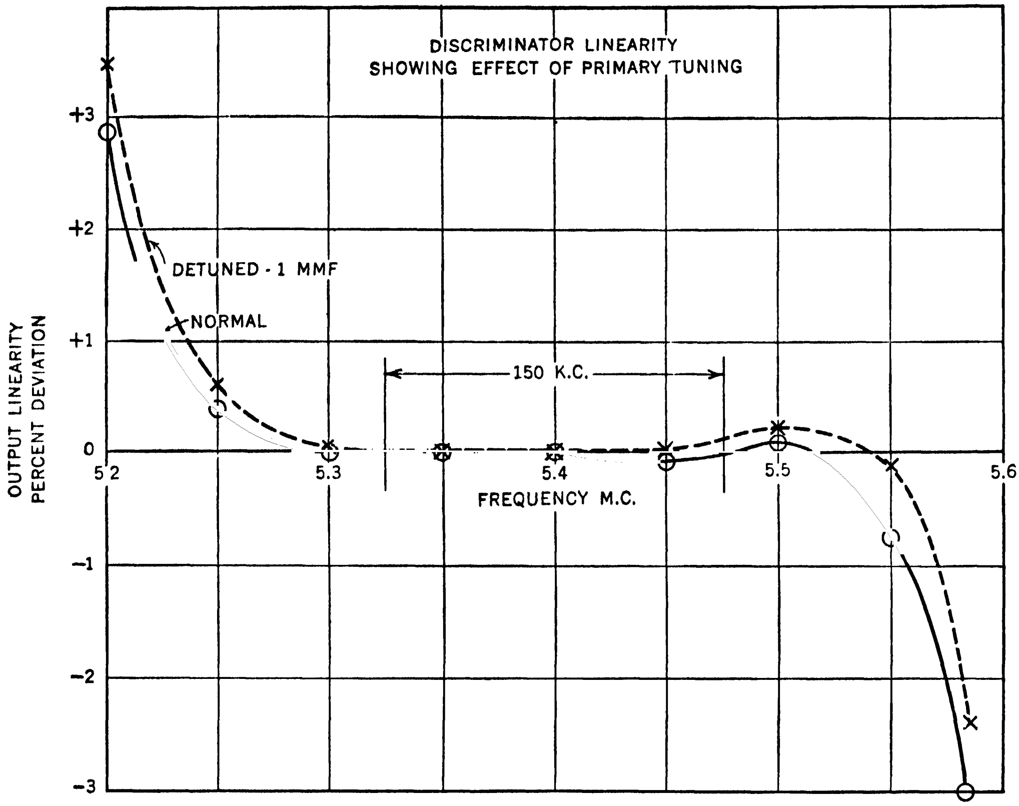

FIG. 7–48. Discriminator linearity showing effect of primary tuning.

There was considerable discussion as to whether a tuned discriminator could meet 0.15-percent distortion or whether it would be necessary to change to a counter type discriminator.

"Accordingly, a very broad-band tuned discriminator was constructed with provision for making precision point-by-point measurements of its characteristics. Frequency was measured with an accuracy of 0.01 percent by comparison with harmonics of a crystal-controlled frequency standard. The d-c output voltage was measured by comparison with a stable voltage source using a precision divider. The frequency and the comparison voltage were changed in equal increments, and the difference between the actual output voltage and the comparison voltage was measured. The resultant data are the deviations from the desired linear relation between frequency and output voltage. These data are plotted in Figure 7–48 with the ordinate scale showing the deviations from linearity expressed as a percentage of the total voltage change for a 150 kilocycle change in frequency. It is seen that the maximum deviation over a 150-kc bandwidth is approximately 0.1 percent for the properly tuned primary and approximately 0.15 percent for the case of 1-$\mu\mu$f change in tuning from the optimum. It is reasonable to presume that the percentage of total harmonic distortion generated by such a detection characteristic cannot exceed the maximum percentage deviation from linearity of the characteristic.

"This investigation proved that the tuned discriminator is capable of providing linear frequency-modulation detection with a distortion in the order of 0.15 percent, and that the amount of detuning likely to be encountered with the change in capacitance due to changing tubes produces negligible effect on distortion.

"*Test Equipment.* Having made the decision to use the tuned discriminator in the new monitor and the same basic circuit as in the original instrument, it then became necessary to design test equipment to prove the performance under actual modulation. Such test equipment is also required during production testing where it would be practically out of the question to use the precision point-by-point method for aligning each discriminator.

"When the specifications for the test equipment are considered, the problem becomes more difficult. The monitor is called upon to meet a distortion factor of 0.25 percent. Therefore, the test equipment, which includes a precision frequency-modulation generator, must in itself generate a frequency-modulated wave having in the order of 0.1-percent harmonic distortion. This tolerance, in turn, is divided internally in the generator between the audio oscillator and the modulator so that each should have less than 0.1-percent distortion. Then, of course, a test discriminator is needed to prove the performance of the generator and such a discriminator in its turn should have much less than 0.1-percent distortion to be of much use in testing the generator.

"As a practical solution to these difficulties, it was decided to build a precision F-M generator and a test discriminator having a different principle of operation from the one in the monitor, but not necessarily lower distortion because that would be too difficult to attain. Then, in making measurements, the signal generator is lined up as well as may be with the test discriminator. The generator signal is then applied to the monitor under test and the monitor is lined up for minimum distortion. If this is excessive, then the generator and the test discriminator and, if necessary, the monitor, too, are readjusted until both discriminators simultaneously show distortion less than the prescribed amount. The simultaneous use of two discriminators of different type makes it almost a certainty that there is no appreciable cancellation of distortion taking place between the monitor and the generator because of detection characteristics which are equally curved but in opposite directions.

"The signal generator employs a reactance tube modulator with considerable negative feedback to help minimize the distortion.

"*Limiting.* Since the discriminator used in the monitor is sensitive to amplitude variations as well as to frequency variations, it is essential to use limiting. Otherwise, any slight variation from a flat i-f response produces amplitude modulation which, in turn, produces additional discriminator output. In general, the additional output resulting from the amplitude modulation causes considerable distortion unless the circuit producing the amplitude modulation happens to have a V-shaped deviation from a flat response. Furthermore, limiting is necessary to reduce the allowable minus 50-db level of amplitude-modulation noise on the transmitted wave. Perhaps the simplest method of limiting is the use of a saturation level of signal at the grid of the discriminator amplifier. This results in a discriminator level which is very nearly independent of input level over a wide range.

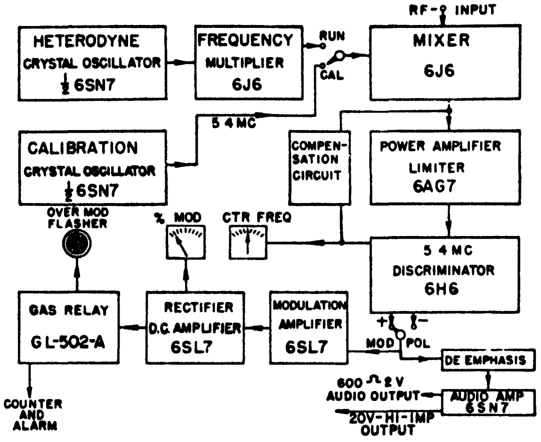

FIG. 7–49. Block diagram of General Electric BM-1-A f-m station monitor.

"Limiting in itself introduces another problem, however, when precision measurements of center frequency are required. It is found that a spurious change in the center-frequency indication may be obtained as the level at the limiter grid is changed even though the level at the discriminator and the frequency of the applied signal stay constant. This change in indication is obtained from the response of the discriminator to the second and even to the third harmonic of the intermediate frequency. This response, although small, is sufficient to give observable changes in the center-frequency indication as the required accuracy limitation is increased and it was felt desirable to eliminate this effect. During the conditions of limiting, considerable harmonic plate currents are generated and their amount increases with the amount of limiting.

"Fortunately, the change is nearly proportional to grid level. This proportionality allows the effect to be compensated for by introducing into the discriminator a compensating current which is also proportional to grid level but is of opposing phase. Such a current is easily derived from the rectified grid bias. Proper adjustment of the compensating resistor, which is not particularly critical, causes the two currents flowing through the frequency indication instrument, one due to harmonic response and the other derived from grid bias, to cancel each other over a grid voltage range of approximately 25 percent.

"This is a sufficient range for this application, particularly since the signal level from the transmitter must be maintained practically constant and additional limiting is also provided at the mixer where the transmitter signal is introduced at a saturation level. Thus, the variations in intermediate frequency signal level due to variations in input level are greatly reduced.

"*Description of F–M Broadcast Station Monitor.* A block diagram of the monitor circuit is shown in Figure 7–49. The structure of the circuit is much like that of the earlier F–M station monitor developed by the General Electric Company, including crystal-controlled oscillator, frequency multipliers, mixer, discriminator amplifier, audio amplifier, modulation amplifier, overmodulation flasher and indicating instruments. The position of the new compensating circuit is indicated on the block diagram.

"In general, the setting of the r-f input level will be an installation adjustment and, once the coupling loop at the transmitter is set to give the correct indication of input level at the monitor, it need not be readjusted. The monitor will operate satisfactorily over approximately a 2 : 1 input power range."

General Specifications—

Power Supply: 105 to 125 volts, single-phase, 50/60 cycles with commercial stability. Power consumption—approximately 170 watts.

R-f Range: 88 to 108 mc.

R-f Input Level: Approximately 1.0 watt into 50 ohms.

Frequency Accuracy: ± 1000 cycles. ± 500 cycles after adjustment to external standard.

Fidelity Monitor: 600 ohms balanced; low frequency level approximately 2 volts rms at 100% modulation; frequency characteristics within ± 0.5 db of standard 75 microsecond de-emphasis curve from 50 to 10,000 cycles and within + 0 db and − 1 db from 10,000 cycles to 15,000 cycles; total harmonic distortion less than 0.5%; noise level at least 70 db below 100% modulation.

Measurement Monitor: Single-ended output, impedance 50,000 ohms; low-frequency level approximately 20 volts rms at 100% modulation; frequency characteristic within ± 0.5 db from 50 to 15,000 cycles of standard de-emphasis curve; and ± 1 db from 15,000 to 30,000 cycles. Total harmonic distortion less than 0.25%; noise level approximately 75 db below 100% modulation.

Ambient Temperature Range: 10° to 40° C.

CHAPTER 8

RADIO-FREQUENCY MEASUREMENTS AND MONITORS

Government regulations, as well as good engineering practice, require that the operators of communication systems provide a means of accurate measurement of the frequency of the emitted wave of their stations. The Federal Communications Commission, through the service of its monitoring stations, measures the frequencies of all services and cites those found operating beyond the authorized tolerances. Each service is required to adhere to their assigned frequency within a specified tolerance, except in the case of services assigned to bands of frequencies. In this case, the carrier frequency must be chosen so that the side bands produced by keying or other means of modulation do not extend beyond the limits of the band.

Consequently, radio communication services either operate their own secondary or working standards of frequency, or obtain frequency measurements from organizations engaged in furnishing this service. The United States Bureau of Standards transmits radio frequencies, accurate to better than one part in 10,000,000, which are known as "Standard Frequency Transmissions." These transmissions permit the owners of secondary frequency standards to check the accuracy of their equipment and make adjustments as might be required if any frequency drift has taken place. These standard frequency transmissions are also useful for many other scientific and laboratory uses.

8-1. The Absorption Frequency Meter—One of the simplest frequency measuring devices is the absorption type frequency meter, or wavemeter, which consists of an inductance and capacitance either or both of which may be variable. The drive-shaft of the variable element of the device is equipped with a pointer and scale, one of which moves with the shaft. The scale may be calibrated directly in frequency or may be used with a calibration chart or table. A resonance indicating device, usually a flashlight lamp or sensitive meter, is provided to indicate when the device is tuned to resonance with the circuit under measurement. Resonance is indicated by maximum deflection of the needle of the meter or maximum brilliance of the flashlight lamp. Since a small amount of power is taken from the circuit being measured to actuate the current-indicating device, the instrument is called an absorption meter. The condenser is usually the variable element, and the range of the instrument is extended by the use of several coils of different sizes.

The wavemeter is calibrated by coupling it to a signal generator, oscillator, or other accurate source of known frequency. A calibration curve may be made by plotting condenser settings against frequency or wave length. Because of changes in capacitance or inductance due to temperature, humidity and vibration, it may be necessary to make frequent checks of the calibration.

The absorption frequency meter is not capable of making precision measurements, but a well-made and carefully calibrated instrument will provide accuracies of from 0.25 to 2.0 percent.

One very useful application of the absorption frequency meter is in tuning the stages of a transmitter where several frequency multiplications are made. As an example, one may desire to quadruple a frequency and incorrectly tune the tank circuit of the multiplier to the third instead of the fourth harmonic. A check with an absorption wavemeter will quickly indicate the error.

Although not as accurate as other frequency-measuring devices to be described, the absorption wavemeter is an extremely useful general-purpose instrument. In addition to the application described above, it is also useful for the following purposes:

1. The measurement of the output frequency of an r-f oscillator or amplifier.
2. The measurement of harmonic frequencies at the output of an r-f oscillator or amplifier.
3. The measurement of the frequency of parasitic oscillations.
4. The detection of radio frequency in power circuits or other undesirable points in the circuit.
5. As an indicator of r.f. during the neutralization of an r-f amplifier.

There are many applications in which the power available from the circuit under measurement is insufficient to actuate the indicating device of the wavemeter. When the circuit under measurement includes a grid or plate current meter, resonance can be determined by noting a reaction on either of these meters when the wavemeter is tuned through resonance. The coupling between the wavemeter and the circuit being measured should not be too close otherwise the mutual inductance of the two circuits may change the frequency of either or both.

Should the wavemeter employ a sensitive thermocouple type r-f galvanometer as a resonance indicator, considerable care must be exercised not to

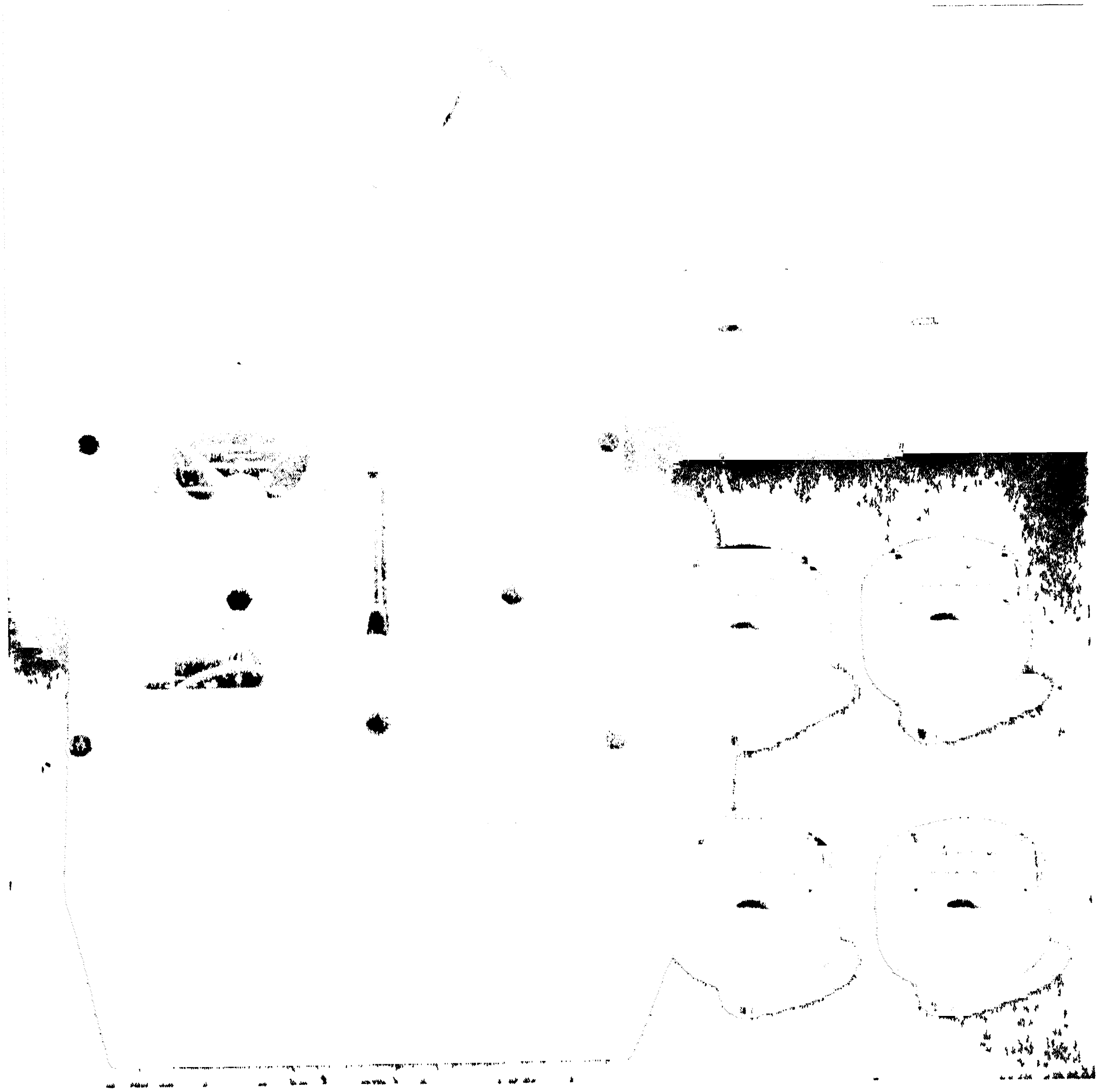

FIG 8-1. General Radio type 724-B precision wavemeter

couple the instrument too closely to the source of power, as a slight overload is usually sufficient to destroy permanently the thermocouple unit of this type of instrument.

8-2. The General Radio Type 724 Precision Wavemeter—The tuned-circuit wavemeter, long since displaced for highly precise work by crystal standards, nevertheless remains one of the most useful general-purpose instruments in the radio laboratory. This is particularly true of the type 724 precision wavemeter, which has been for many years an accepted standard in the industry.

For such applications as the preliminary line-up of radio transmitters and the rapid checking of oscillator frequencies, this precision wavemeter fills a definite need in the frequency measurement field. The variable condenser is a General Radio type 722, specially designed for the purpose, with plates shaped to give a scale that is linear in frequency. The precision of setting is better than one part in 25,000. The plug-in coil mounting allows the coil to be rotated to obtain different degrees of coupling.

Newly developed crystal rectifiers and newly derived design formulas for inductors have made it possible to improve the performance of the wavemeter considerably. In the latest model, type 724-B, the vacuum-tube detector used in previous models has been replaced by a germanium crystal, thus eliminating the need for batteries and considerably simplifying the maintenance problem. Both selectivity and sensitivity are enhanced owing to a 2:1 improvement in the loading effect of the detector on the tuned circuit.

Selectivity and sensitivity are also greatly improved by a complete redesign of the inductors to obtain higher values of the storage factor, *Q*. All inductors have considerably higher *Q*'s than formerly, with the greatest gain obtained on the 16 to 50 kc coil, where the improvement is of the order of 6:1. As a result, this coil is now calibrated to the same accuracy as the others, namely, 0.25 percent.

8-2a. Specifications

1. *Frequency range.* 16 kc to 50 mc.
2. *Accuracy.* ± 0.25 percent.
3. *Calibration.* The calibration is supplied in the form of a table of calibrated points. Linear interpolation between these points is used to obtain settings for other frequencies.
4. *Condenser.* Precision worm-drive type. The setting is indicated on the dial and drum and is controlled from the front of the panel. There are 7500 divisions for the entire 270 degree angular rotation of the rotor. The precision of setting is better than one part in 25,000. The plates are shaped to give an approximately linear variation in frequency with scale setting.
5. *Inductors.* Coils are wound on isolantite forms and enclosed in molded phenolic cases. Seven coils are used to cover a frequency range between 16 kc and 50 mc.

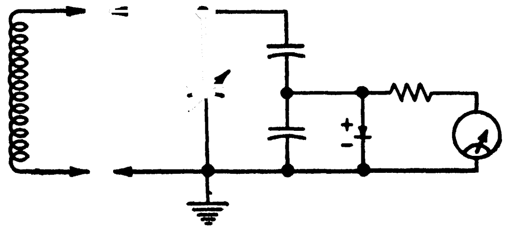

FIG. 8-2. Circuit arrangement of the General Radio type 724-B precision wavemeter.

6. *Resonance indicator.* A germanium crystal rectifier is used with a microammeter to indicate resonance. The indicator is coupled to the tuned circuit through a capacitive voltage divider.
7. *Crystal.* Type 1N34 germanium crystal rectifier is used.

8-3. Heterodyne Frequency Meters—The heterodyne frequency meter represents an improvement over the absorption type wavemeter in providing accurate measurements of frequency. In its best form the heterodyne frequency meter consists of a completely shielded, stable r-f oscillator which may be tuned over the desired frequency range. The tuning element of this oscillator is usually equipped with a vernier type dial to permit accurate reading of the dial setting. The oscillator is accurately calibrated and the data recorded in the form of a calibration chart showing dial settings versus frequency, or, in some cases, the divisions of the dial are directly engraved in frequency. In most heterodyne frequency meters a simple detector and audio amplifier circuit, together with a very small antenna to pick up the frequency to be measured, are provided. The antenna also serves to radiate a small portion of the oscillator output making it possible to employ an external receiver for heterodyne measurements if desired.

Precision heterodyne frequency meters are provided with an auxiliary quartz-crystal-controlled (fixed frequency) oscillator by means of which points on the dial may be checked against an accurate frequency. When such a crystal calibrating oscillator is provided, the accuracy of frequency measurements is improved.

In making frequency measurements with the heterodyne frequency meter, the instrument is placed near the source of frequency to be measured so that a small portion of the signal will be intercepted by the pick-up antenna. The dial of the heterodyne frequency meter is then tuned until a beat note is heard in the headphones. This beat note is a beat between the signal being measured and the oscillator frequency of the meter. The dial is then carefully adjusted until a zero beat note is obtained. When this is done, the heterodyne frequency meter is tuned exactly to the unknown frequency (or a simple harmonic relation exists between the two frequencies). This frequency can then be read directly from the dial of the meter or obtained from the calibration chart.

On the following pages are described two commercially available heterodyne frequency meters. The accuracies obtained with these instruments are representative of the accuracies to be expected from this type of device.

8-4. Link Type 230-D Crystal Frequency Monitor—The Link 230-D monitor can be used for checking frequencies of crystal-controlled transmitters, for tuning master-oscillator controlled transmitters to a predetermined frequency, and for checking the actual frequency of operation. It can be used as a variable or fixed-frequency signal generator for testing and aligning receivers and, finally, as a monitor receiver to check the quality of transmissions.

Two oscillators are provided in the 230-D monitor. One is a stable, calibrated, variable oscillator, controlled by a vernier dial located on the front panel. The other is a crystal oscillator circuit so designed that no tuning is necessary regardless of the frequency of the crystal used. Wide changes in circuit constants will not affect the frequency of the crystal oscillator. The crystal supplied is ground to a frequency tolerance of better than 0.005 percent

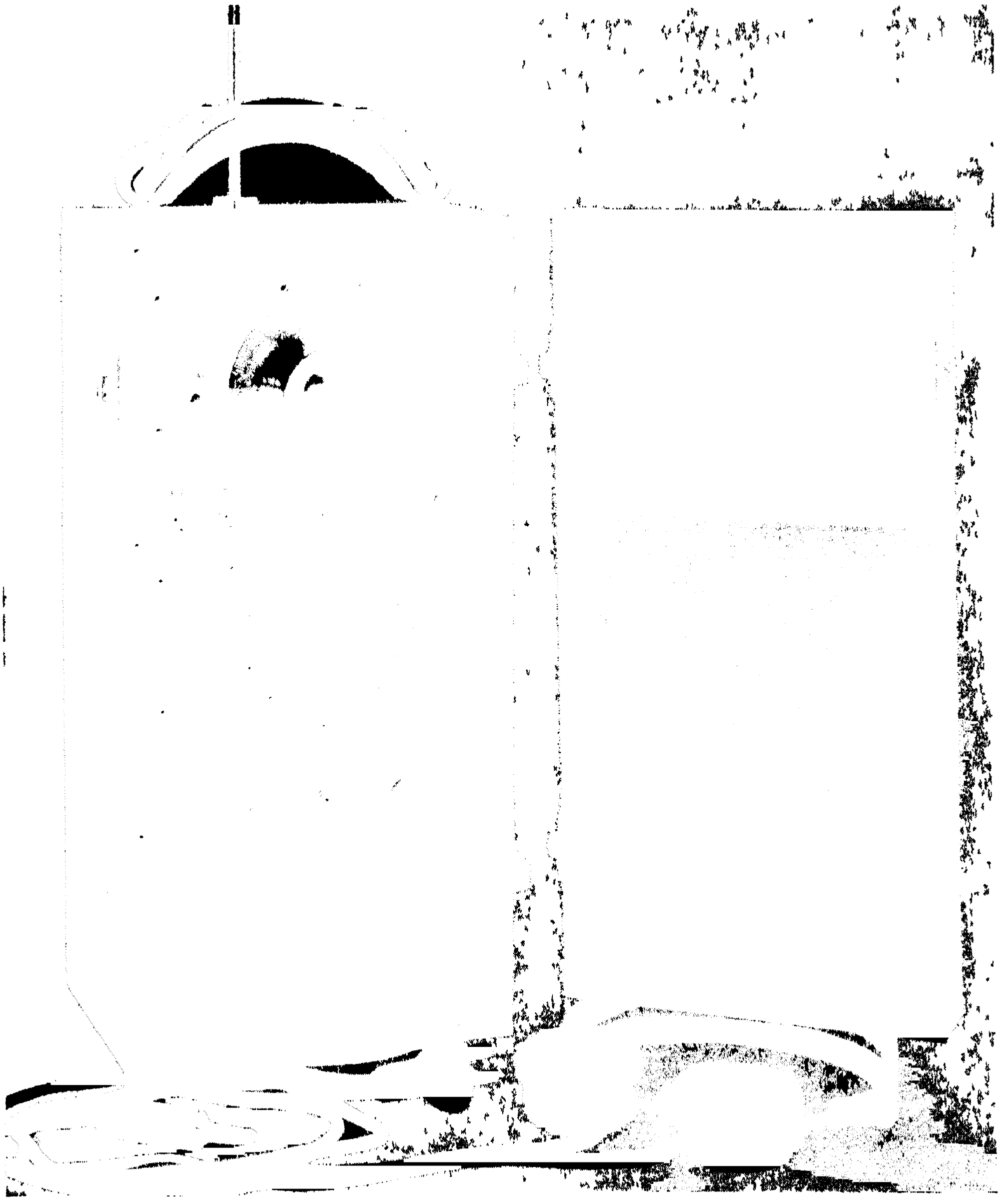

FIG. 8-3. Link type 230-D crystal frequency monitor

of the operating frequency. The variable oscillator is normally designed to cover ±0.2 percent from any of the usual police and emergency frequencies in the 30 to 40 mc band. It is calibrated accurately and a calibration curve is attached to the inside of the front cover. Either oscillator can be turned on or off by means of switches located on the front panel.

A gridleak detector and audio amplifier are incorporated in the monitor, as well as a power supply for a-c operation. A 25-foot a-c cord and headphones are stored in a compartment at the bottom. A short antenna, normally plugged into the top of the monitor, can be removed and clipped into spring holders provided on the inside of the cover. With the front cover in place, the unit can be conveniently carried by means of the leather handle mounted on top of the case as shown in Figure 8–3. The physical dimensions of the instrument, with the cover in place, are: height 16½ inches, width 8 inches, and depth 8½ inches.

When the unit is used for aural monitoring of the output of an A–M transmitter, both oscillators are turned off. In this condition, the receiver will give good headphone reception even when located a considerable distance from the transmitter.

For checking transmitter frequencies, either oscillator is turned on and the beat note between the received signal and the local oscillator can be heard in the phones. By turning on both oscillators at the same time and tuning the variable oscillator to the crystal frequency, the variable oscillator can be re-calibrated at any time. For this purpose, a vernier adjustment is provided so that the variable oscillator can be re-set to exact calibration, as given by the curve, thus correcting for temperature drift, tube aging, tube replacements, or other considerations. When so adjusted, the monitor is (for the time being) accurate within 0.005 percent *for frequencies within 0.2 percent of the specified operating frequency.*[1]

For aligning receivers, either oscillator will emit a carrier wave from the plug-in antenna. The receiver can be brought into tune by means of the variable oscillator and then checked directly against the crystal.

8–4a. Adjustment—The normal operation of the monitor is accomplished as follows: The power cord is plugged into any 110–120 volt, 50 to 60-cycle a-c source. After a few minutes' warm-up, the main tuning dial is set at 50, a pair of phones and the antenna rod are plugged in, and both the crystal and variable oscillator switches are turned to the ON position. By means of the small knob adjustment to the left of the tuning dial, the beat note, heard in the phones, is adjusted to zero beat. This operation puts the variable oscillator in exact calibration at the operating frequency. Other frequencies in the operating range can be read from the calibration curve furnished with the monitor. This curve is furnished for the convenience of the user and is not expected to be as accurate as the crystal check point.

8–4b. Checking Transmitter Frequency—It is first necessary to adjust the monitor to zero beat as described above. To check the frequency of a transmitter, place the monitor close to the transmitter, so that a small voltage can be picked up by the monitor antenna. With only the variable oscillator on, tune the monitor to zero beat and read the micrometer dial, after which the correct frequency can be read from the chart.

The micrometer dial furnished with the 230–D has 100 divisions and a micrometer scale for accurately reading to 1/10 division. Since the full scale of the dial represents about 0.4 percent of the operating frequency, 1/10 dial division will represent a 0.0004 change in frequency. Thus the monitor can

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[1] The accuracy of any such device is obviously best at the crystal check point (or points).

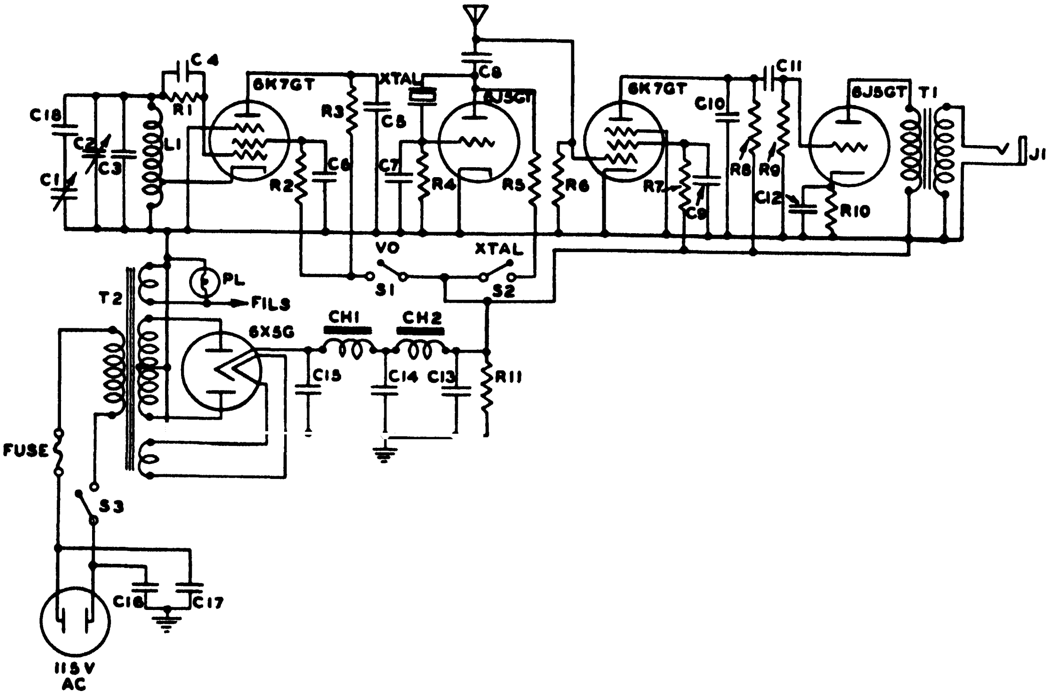

FIG. 8–4. Schematic circuit diagram of Link type 230-D crystal frequency monitor.

be read to at least ten times the guaranteed accuracy of the variable oscillator.

A heterodyne frequency meter of this type is equally well suited to measuring the carrier frequency of either an A-M or an F-M transmitter. In either case it is necessary to make the measurement without modulating the transmitter, in order to get a clean beat note.

8-4c. Checking Frequency Modulation—The gridleak detector is not suited, of course, for aural monitoring of modulation in conjunction with an F-M transmitter, but is well adapted to measuring peak frequency deviations by the carrier null method. This method of measuring deviation makes use of the fact that if a certain audio frequency is used to modulate an F-M transmitter, the relative magnitude of the carrier and side bands will vary as the amplitude of the modulating frequency is varied. The amplitude of the carrier will reach zero when the peak deviation is 2.40, 5.52, 8.65, etc. times whatever audio frequency is being used to modulate the transmitter. This is termed the Bessel method of frequency-deviation measurement.

In order to illustrate the technique used to measure deviation in this manner, let us assume a common practical problem. Suppose that it is necessary to determine the audio level required to produce ± 15 kc deviation in a given transmitter. The first carrier null point occurs when the deviation is 2.40 times the modulating frequency. Therefore if we use 15,000/2.40, or 6250 cycles, as the modulating frequency, the audio input level at the first carrier null point will be the required value. This simple operation is accomplished as follows:

1. Set up the 230-D monitor and adjust the variable oscillator to beat against the transmitter carrier, without modulation. Tune for some easily distinguishable beat note such as 500 cycles.
2. Apply an audio input voltage of 6250 cycles to the transmitter and gradually increase the audio level. As the level is measured, other heterodyne beats will be heard, but they will be of the order of 6000 cycles and the ear can easily distinguish the original 500-cycle beat against the carrier.
3. As the audio input is varied a very definite point will be noted where the amplitude of the heterodyne beat against the carrier reaches a null or minimum level. The audio input level at this point will be the value required to cause ± 15-kc deviation.

If the audio input level is increased further, other carrier null points can easily be distinguished at 6250 × 5.52 or ± 34.5 kc, and 6250 × 8.65 or ± 54 kc. This monitor thus serves the user of F-M as well as A-M equipment.

The use of the Bessel method of frequency deviation is described in detail in Chapter 7.

8-5. General Radio Type 720-A Heterodyne Frequency Meter—The type 720-A heterodyne frequency meter is designed for measuring frequencies between 10 mc and 3000 mc. It contains a calibrated oscillator, a detector, and an audio amplifier. The oscillator frequency can be varied continuously between 100 mc and 200 mc. The unknown frequencies are measured by producing beats with the calibrated heterodyne oscillator. Beats may be produced between the fundamentals of the unknown source and the heterodyne oscillator, between harmonics of the unknown frequency and the heterodyne fundamental, between the unknown fundamental and harmonics of the heterodyne oscillator, or between the harmonics of both the unknown source and the heterodyne oscillator. The main dial of the frequency meter has essentially a logarithmic calibration, and one-half turn of the vernier dial corresponds to one percent change in frequency. An elementary circuit diagram is given in Figure 8-6.

FIG. 8-5. The General Radio type 720-A heterodyne frequency meter.

8-5a. Operation—A pair of headphones plugged into the jack marked PHONES is the best means of determining beats. For fairly strong signals, the presence of a beat will be indicated by a downward deflection of the panel meter. Exact zero beat will result in no deflection of the meter. The beat note will be heard in the small dynamic speaker on the panel if the telephones are unplugged.

The audio-frequency amplifier has a useful bandwidth of 50 kc, hence indications will be obtained on the panel meter when the beat frequency is above the audible range. This feature is useful when the frequency under measurement is unstable and no steady audible beat can be obtained.

Adequate coupling is usually obtained if the instrument is placed in the vicinity of the oscillator whose frequency is to be measured. For high frequencies the length of the antenna, marked INPUT

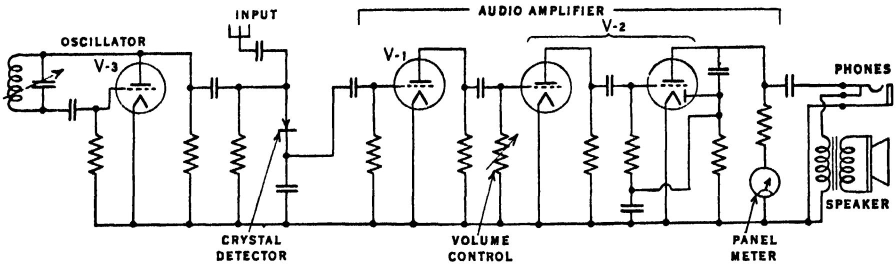

Fig. 8–6. An elementary circuit diagram of the G. R. 720-A heterodyne frequency meter.

on the front panel, can be adjusted to improve signal strength. For frequencies below 100 mc it may be necessary to connect a short wire to the antenna.

1. *Battery.* One Burgess 6TA60 battery is used to supply 90 volts to the plates and 1.4 volts to the filaments of the vacuum tubes. All necessary connections are made by a battery plug attached to a short cable. Filament and plate loads are well balanced, and the battery will give long service in intermittent use. Since the heating-up time of the tubes is very short, the instrument can be turned off if appreciable time' elapses between measurements. The battery should be replaced if the deflection on the panel meter is below one milliampere with the volume control at minimum.

2. *A-c Power Supply.* Type 1261-A power supply fits the battery compartment and, with type 1261-P3 selector plug, supplies the filament and plate voltages for the tubes. To adjust filament voltage to correct value, connect a 1000 ohms/volt voltmeter to filament terminals. With filaments turned on, note voltmeter reading; press push-button switch on the top of power supply unit. Turn screw-driver adjustment on the top of power supply until meter reading does not change when button is depressed. When a-c power supply is used, leave panel switch ON and use switch in power cord to turn instrument on and off.

3. *Tubes.*

V-1 Type 1N5-GT
V-2 Type 1D8-GT
V-3 Type 958-A
Detector 1N21B

Select 958-A replacements for low microphonic noise. Pick to match frequency calibration as follows: 1. Set an external oscillator (which will beat with 100 and 200 mc) to obtain beat note with 720-A set at 100.0 mc. 2. Then set 720-A to get beat note at or near 200.0 mc. 3. Choose 958-A which give beat nearest 200.0 mc.

8–5b. Making Frequency Measurements—1. *Frequencies Between 100 and 200 Mc.* When the frequency to be measured lies within the fundamental range of the type 720-A heterodyne frequency meter, the unknown frequency is read directly from the main dial when a strong beat is obtained. In addition to this beat note other weaker beat notes may be heard. For example, if a fundamental frequency of 150 mc is measured, a strong beat will be obtained at a dial setting of 150.0 mc, and weaker beats may be heard at dial settings of 100 and 112.5 mc. These weaker beats are produced between the second and third harmonics of the unknown frequency and the third and fourth harmonics of the type 720-A oscillator, respectively; 2 × 150 mc = 3 × 100 mc and 3 × 150 mc = 4 × 112.5 mc.

2. *Frequencies Above 200 Mc.* For frequencies which lie above 200 mc the procedure is to start at the high end of the frequency range and to note the successive settings of strong harmonic beats as the frequency of the heterodyne oscillator is progressively reduced. If the frequency at which one beat occurs is divided by the frequency difference between it and a successive beat, the result must be an integer and is the harmonic number of the successive beat. *Example:* A high frequency is measured and strong beats are obtained at 200.0 and 160.0 mc. Subtracting the second beat from the first gives 200.0 − 160.0 = 40.0. Dividing the first beat by this difference gives 200.0/40.0 = 5, which is

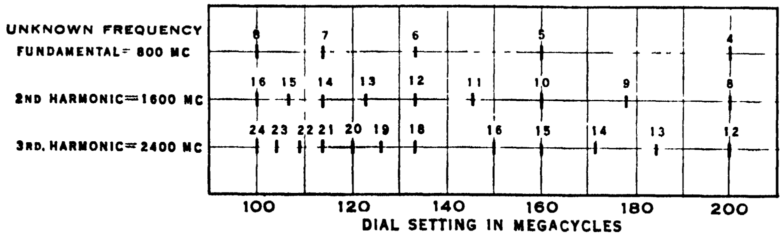

Fig. 8–7. Chart showing possible beats up to the third harmonic with the 720-A heterodyne frequency meter.

the harmonic number of the second beat. Hence, the unknown frequency is 5 × 160.0 = 800.0 mc.

3. *Beats Between Harmonics.* In many cases it will be possible to produce beats between harmonics of the unknown frequency and harmonics of the heterodyne oscillator. These beats will usually be much weaker than the beats produced between the unknown fundamental and the heterodyne harmonics. The chart, Figure 8–7, gives the possible beats up to the third harmonic of the unknown used in the example above.

In general, if the "unknown" frequency is known approximately, a single beat is sufficient to determine the frequency accurately. On the other hand, if the approximate value is not known, it will be necessary to note successive beats until their pattern can be determined as above. Much time can be saved and possible errors eliminated, however, if the unknown frequency is determined approximately by other means, such as an absorption-type wavemeter.

4. *Frequencies Below 100 Mc.* For frequencies which lie below 100 mc, the procedure is to start at the low end of the frequency range and to note the successive settings of beats as the frequency of the heterodyne oscillator is progressively increased. The frequency difference between two successive beat settings is equal to the unknown frequency. *Example:* A low frequency is measured and beats are observed at 105.0, 120.0 and 135.0 mc. The frequency difference between successive beats is 15.0 mc, which is the frequency being measured.

8–5c. Maintenance—The detector is located near the antenna input terminal and is held in place by a ring-shaped spring. A spare detector cartridge (clamped to the left rear corner of the top shelf) is supplied with the instrument.

When the dial is rotated rapidly, a drone from the gear train plus some microphonics from the oscillator tube should be heard in the telephones. If these sounds are not heard, either the oscillator is not working or the detector unit is defective.

The detector can be tested with an ohmmeter operated from a 1.5-volt battery. The $R \times 100$ range of a Weston model 663 ohmmeter is satisfactory for this test. For proper operation, the ratio of back resistance to forward resistance should be 30 to 1 or greater with the back resistance greater than 10,000 ohms and the forward resistance less than 1,000 ohms. The detector will work with ratios of back to forward resistance less than 30 but efficiency of detection is decreased.

8–6. Measurement of High Frequencies by Lecher Wires—At high frequencies, where the magnitude of a wave length is small, it becomes practical to measure wave length directly by measuring the length of the standing wave pattern set up on a two-wire parallel transmission line by the frequency to be measured. This method of measuring wave length was used by E. Lecher as early as 1890, and for this reason parallel lines used for this purpose are known as "Lecher wires." A similar method of frequency measurement was employed in the experiments of Hertz and Lodge.

Figure 8–8 shows a schematic diagram of such a parallel-line measuring system. The parallel wires, which may be of any length but should be at least one wave length long, are loosely coupled to the circuit to be measured. Inasmuch as the far end of the line is open, standing waves will be set up on the line. As the current-measuring device, usually a thermocouple ammeter, is moved along the line, points of maximum current (current loops) will be indicated by maximum deflection of the indicating instrument. The distance from one current loop to the next, which can be measured with a yardstick or similar device marked off in metric units, will be equal to one half wave length of the frequency being measured.

If this distance is measured in meters, the frequency in megacycles will be $f = \frac{150}{\text{distance in meters}}$; if measured in inches, the frequency in megacycles will be $f = \frac{5905.5}{\text{distance in inches}}$.

In practice, it has been found that more accurate measurements are possible by measuring the distance between current minima (current nodes) rather than current maxima (current loops) as the current nodes are more sharply defined. If accu-

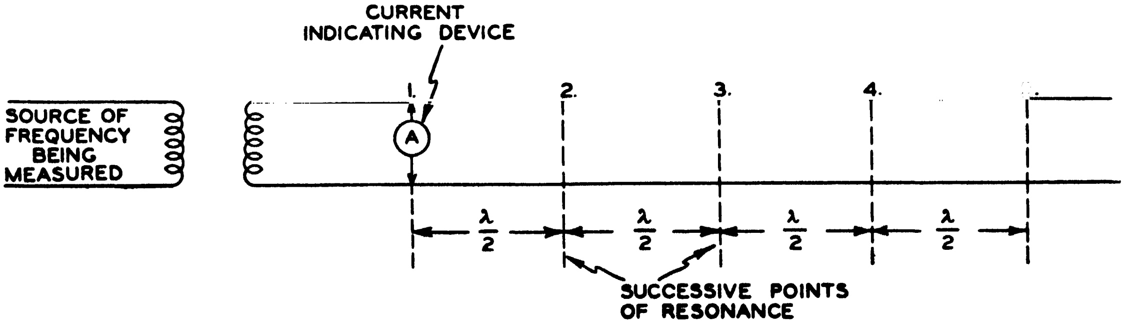

FIG. 8–8. Schematic of Lecher wires used for measuring wavelength of very high frequencies.

racy is desired, it is also important that only air dielectric be present between the wires in the section of the line being used.

The accuracy to be expected of frequency measurements made by means of Lecher wires is largely a matter of the care exercised in making the measurements. Very carefully made measurements may reach an accuracy of 0.1 percent.

8–7. Multivibrators—Most secondary or working standards of frequency employ a quartz-crystal-controlled oscillator, which generates a frequency that is very stable and constant over long periods of time. These oscillators usually operate on a rather low frequency, 50 kc and 100 kc being frequently employed. The frequency of such an oscillator is periodically checked against, and synchronized with, a more precise standard, such as the Bureau of Standards "standard frequency transmissions." Such an oscillator is very useful in frequency measurements as other devices may be calibrated using this oscillator as a standard.

The usefulness of such a "standard" oscillator may be still further expanded if a means is provided whereby the frequency may be both divided and multiplied, thereby making available a large number of frequencies, each with the same accuracy as the original oscillator, which may then be employed for direct comparison with unknown frequencies. Frequency multiplication presents no unusual problems as standard methods of harmonic production and frequency multiplication may be employed. Frequency division, on the other hand, presents a different problem and is usually accomplished by means of the multivibrator, sometimes known as the relaxation oscillator (see Figure 8–9).

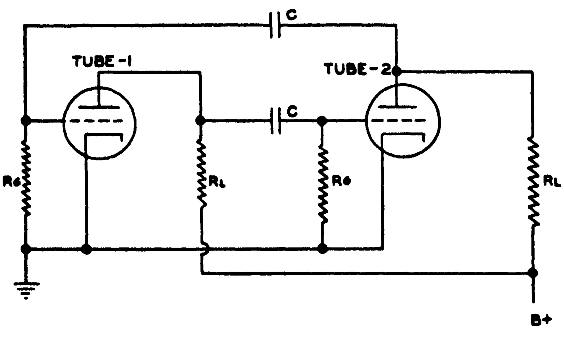

Fig. 8–9. Circuit of the multivibrator. The frequency of oscillation is determined by the values of resistance and capacitance.

Essentially, the multivibrator is a resistance-capacitance coupled amplifier with its output circuit feeding sufficient energy back to the input in the proper phase relationship to cause oscillation. The frequency of this oscillation is determined by the time constant of the resistance and capacitance values of the circuit components. The output wave form is very irregular and therefore contains a high order of harmonics. The oscillations of the multivibrator are quite unstable, but can be controlled at a definite frequency if a suitable controlling voltage from another source, the frequency of which corresponds to the fundamental or to a higher harmonic of the fundamental frequency of the uncontrolled multivibrator, is properly introduced into the circuit. When the control frequency is introduced, the multivibrator locks into step with the control frequency.

A ratio of multivibrator frequency to controlling frequency of 10 is a value often encountered in practice. Thus, the voltage from a 100-kc oscillator may be employed to control a 10-kc multivibrator, and the output of the 10-kc multivibrator in turn employed to control a 1-kc multivibrator. Three accurate frequencies, 100 kc, 10 kc, and 1 kc, are thereby available for measurement work.

In precise standards of frequency, the 1-kc multivibrator frequency is often employed to operate a synchronous motor driven clock. These clocks are designed to keep true time when driven by a frequency of exactly 1000 cycles; therefore, by comparing the indicated time with standard time a measure of the accuracy of the driving frequency is obtained.

8–8. Locked Oscillators—In addition to multivibrators, locked oscillators are sometimes used to provide known frequencies at convenient points such as 100 kc and 1000 kc.

Referring to Figure 8–10, the circuit is comprised of a 50-kc input amplifier utilizing a resistance-capacitance coupled pentode tube feeding locking voltage to an oscillator tube locked on 100 kc. This tube is self-oscillating but its constancy of frequency is dependent upon the magnitude and constancy of the frequency of the injected voltage. The output of this locked oscillator tube is coupled to a buffer amplifier and then to a harmonic amplifier with an inductive plate load which provides an output rich in harmonics.

Should the oscillator become unlocked, a rough, modulated signal will be produced similar to that encountered when a multivibrator steps out of control. In such a case, it is necessary to increase the control voltage.

8–9. General Radio Frequency Standards—The determination of frequency directly in terms of time is a fundamental measurement; since frequency is the *time* rate of recurrence of a cyclical phenomenon. A *primary* standard of frequency is, therefore, defined as one whose frequency is determined directly in terms of time. A *secondary* standard is one whose frequency is determined by comparison with a primary standard, or by comparison with other secondary standards, some one of which was originally compared with a primary standard.

It is to be noted that the above classifications of frequency standards have nothing to do with the

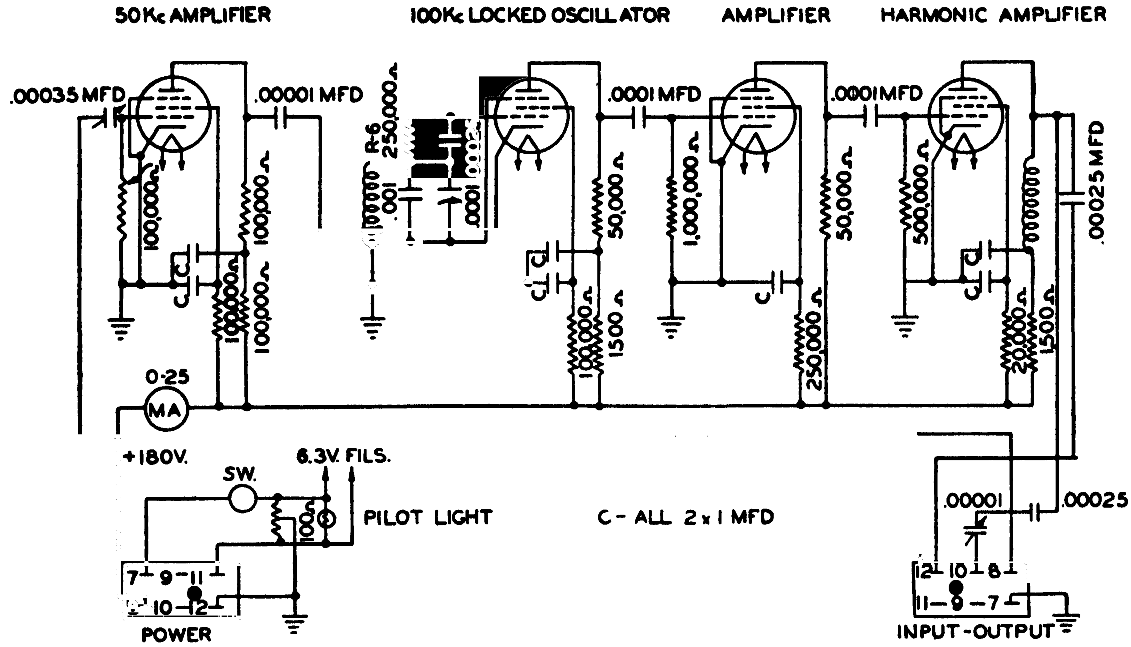

FIG. 8-10. 100-kc locked oscillator and harmonic amplifier.

accuracies of the standards. In fact the same standard is logically classed as a primary standard if checked directly against time, and as a secondary standard if checked against standard frequency transmissions (representing a distant primary standard).

In practice, the responsibility of establishing and maintaining accurate time determinations by astronomical observations is not assumed by the individuals desiring a primary standard of frequency. The time determinations are carried out by observatories especially equipped for the purpose. The results are made available to a large number of users by radio and wire transmission. In the United States, the U. S. Naval Observatory transmits high-precision time signals by radio through the facilities of the U. S. Naval Radio Service. Transmissions on several frequencies are available several times a day and can be received nearly all over the world.

The user of a primary frequency standard can then conveniently determine the frequency of the standard in terms of the standard time interval sent to him by radio. In the General Radio equipment means are provided for quickly and easily making this comparison. For the most precise results, the errors of the transmitted time signal must be taken into account. Correction data may be obtained by applying to the Superintendent, U. S. Naval Observatory, Washington, D. C.

Since the astronomical clocks now used at the Naval Observatory are piezo-electric oscillators, similar to those used in accurate frequency standards and since, through close cooperation of the U. S. Naval Observatory and the National Bureau of Standards, the piezo-electric oscillators of the latter's primary frequency standard are checked in the same way as the former's astronomical clocks, the comparison with time is, in effect, carried out by the observatory. The standard frequency transmissions sent out by the Bureau of Standards consequently represent a primary standard of high precision available to all who can receive the transmissions. Where such transmissions can be received, it is generally more convenient and much quicker to make the comparison by frequency than by time. For information and schedules of transmission of standard frequencies, apply to the Radio Division, Bureau of Standards, Department of Commerce, Washington, D. C.

Because of the vagaries of high frequency transmission, many users rely on checks against time as a reserve. They also use the primary standard as a high-precision clock for laboratory timing purposes.

As so far considered, the precision oscillator is a single-frequency device. For practical utility it is necessary to obtain from this single frequency many other frequencies, both above and below the standard frequency, for convenience in measurements. Since most of the precision oscillators operate in the region of 50 to 100 kc, it is necessary to divide the frequency to obtain a value such that an easily constructed synchronous motor can be used to count the number of cycles executed by the precision oscillator in a standard interval of time. For measurements of high radio frequencies, it is necessary to multiply the standard frequency to obtain useful frequencies in the range of the frequency being measured. Both of these operations are readily performed by a controlled relaxation oscillator, known as a multivibrator.

An oscillator of this type is characterized by its susceptibility to control by an introduced voltage, the frequency of which lies near the fundamental, or low-order harmonic, frequency. In the controlled condition, the relaxation oscillator locks into step with the control voltage, and the frequency bears an integral relationship to the frequency of the controlling voltage.

8-9a. The Primary Frequency Standard Type 1100-AP—The elements of a primary frequency standard, General Radio type 1100-AP, are shown in Figure 8-11.

The frequency of the precision oscillator is 100 kc, which is divided successively by factors of 10 to obtain multivibrator fundamental frequencies of 10, 1, and 0.1 kc. A fourth multivibrator operating at a fundamental frequency of 100 kc, provides a large number of harmonics at 100 kc intervals for use at high radio frequencies. Harmonics of the 10 kc multivibrator are similarly used. In the audio-frequency and low-frequency range (up to one or two hundred kc) a cathode-ray oscilloscope is used to obtain hundreds of known frequencies. This is simpler than trying to make use of harmonics of the low standard frequencies.

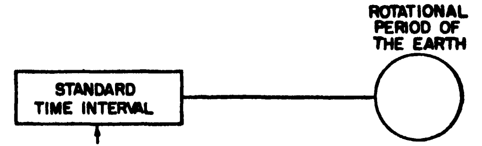

FIG. 8-11. Functional block diagram of the frequencies obtainable from type 1100-A frequency standard.

The range of useful output frequencies obtainable from the General Radio Primary (or Secondary) Frequency Standard is indicated in Figure 8-11. Complete specifications are given in Section 8-10.

This frequency standard is the result of many years of continuous development in the General Radio laboratories. The quartz bar (and mounting), the oscillator circuit, and the temperature-control system used in the standard make possible a stability of a few parts in 10^8 over periods of several months, and a short-period stability of approximately 2 parts in 10^9. The quartz bar and its mounting are shown in Figure 8-12. The bar vibrates in its second-harmonic extensional mode, and is held at its two nodes in a spring suspension mounting in such a manner as to introduce a minimum of damping. Electrodes are formed directly on the surfaces of the quartz. The cross-sectional dimensions of the bar have been so chosen that the temperature coefficient of frequency is zero in the vicinity of the operating temperature of 60° C.

FIG. 8-12. View of the 1190-A quartz bar used in 1100-A frequency standard, with cover removed, showing the spring suspension.

The temperature-control system holds the temperature of the quartz bar constant to better than 0.01° C.

A bridge-type oscillator circuit is used, shown in schematic form in Figure 8-13. In this circuit, the crystal vibrates at its series resonant frequency and the amplitude of oscillation is constant.

8-9b. The Secondary Frequency Standard Type 1100-AQ—In the past there was a useful field for frequency standards of less than the best possible precision, such standards being checked frequently against standard frequency transmissions. These standards could be manufactured at a lower cost than the more precise standards and consequently were used in many applications where price was a governing consideration.

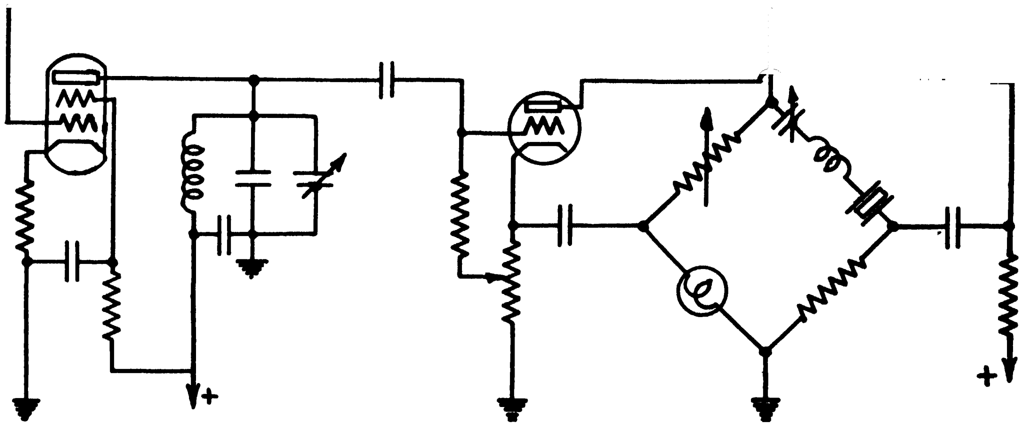

FIG. 8–13. Elementary circuit of the bridge-type piezo-electric oscillator used in the 1100-A frequency standards.

At present the demand for more accurate secondary standards, coupled with less expensive designs for primary standards, makes it undesirable to make two types of standard. Consequently, the same component units are offered for use as a secondary standard—the precision oscillator, and multivibrator and power supply unit, but without the syncronometer unit. This latter unit can be added later, if desired.

8–9c. Frequency Measurement—The next step, after establishing a series of standard frequencies embracing a portion of the frequency spectrum in which measurements of frequency are to be made, is to evaluate any unknown frequency in terms of one of the standard frequencies. Any unknown frequency will lie between two of the standard-frequency harmonics as shown in Figure 8–14. The simplest process is to determine the difference in frequency between the unknown frequency and the nearest of the standard frequencies. This difference is added to the standard frequency if the unknown lies above the standard, or subtracted if the unknown lies below the standard frequency.

For evaluating the frequency difference, *A* or *B* (Figure 8–14), a convenient method consists of beating the standard and unknown frequencies in a detector, and measuring the beat frequency by comparison with a calibrated audio oscillator as indicated in Figure 8–15.

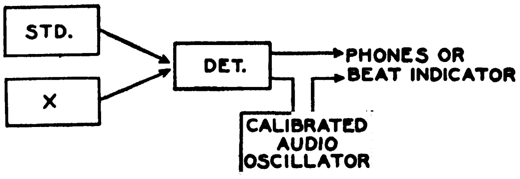

FIG. 8–15. Functional diagram showing the operation of the direct-beating method of frequency measurement.

The type 1105-A frequency measuring equipment has been designed as an assembly of the necessary instruments for measuring unknown frequencies in terms of standard-frequency harmonics obtained from the type 1100 frequency standard. This assembly includes an interpolation oscillator and comparison oscilloscope for measuring audio and beat frequencies as well as the necessary radio-frequency detectors and calibrated oscillators used in measuring the higher frequencies. Complete

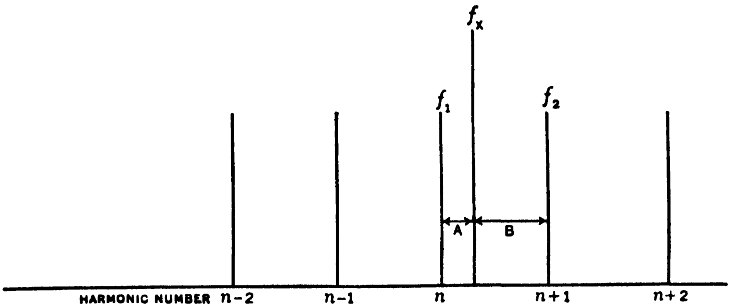

FIG. 8–14. This diagram shows the relation between an unknown frequency and a standard harmonic series.

descriptions of this equipment are given in Section 8-11.

8-10. General Radio Type 1100-A Frequency Standards—The type 1100-A frequency standards are completely new and highly precise standards of frequency, operating on the principles outlined in Section 8-9. Two models are available, the type 1100-AP primary standard and the type 1100-AQ secondary standard. The same basic elements are used in each, and there is no difference in accuracy and stability between the two assemblies.

The primary standard is provided with a Syncronometer (synchronous motor clock for evaluating its frequency directly in terms of standard time. The secondary standard has no synchronometer. All other specifications are identical with those for the primary standard.

Harmonic series based on fundamentals of 0.1, 1, 10, and 100 kc are available at its output terminals to furnish usable standard frequencies over a wide range. The accuracy of all output frequencies is the same and is better than five parts in ten million over periods of several months.

The primary standard is an excellent national standard of frequency for communications ministries, and with the type 1105-A frequency measuring equipment, can be used to monitor or to measure the frequencies of radio stations. It is also suitable for use as a standard clock by observatories. Research laboratories and radio manufacturing plants should use the primary standard whenever the requirements make it advisable to have an independent check against time.

For many uses the timing feature of the primary standard is not needed, and the secondary standard, which offers the same stability at a lower price, can be used. With the secondary standard, an accurate check upon its frequency can be made by a comparison with standard-frequency radio transmissions such as those of the National Bureau of Standards at Washington. This comparison is adequate to evaluate the frequency of the standard to a few parts in one hundred million.

8-10a. Type 1103-A Synchronometer—This panel includes a 1000-cycle synchronous motor for effectively counting the number of cycles executed by the standard piezo-electric oscillator in a standard time interval. A large, illuminated, 24-hour dial with a long sweep hand makes for easy visibility. A microdial contactor operating once each second, and calibrated in hundredths of a second, is provided for comparison with time signals. The microdial mechanism can be phased by means of a panel control. Comparison of the synchronometer reading with standard time can be made on the microdial scale to one part in ten million over a 24-hour interval. The 1000-cycle synchronous motor is started by a 60-cycle motor controlled by a push-button on the panel.

8-10b. Type 1102-A Multivibrator—This unit contains four multivibrators of 100, 10, 1, and 0.1 kc frequencies, the power supply for the entire standard, and the control circuits of the temperature-control system of the type 1101-A piezo-electric oscillator. Concentric shielded connectors are provided for 100-kc and 10-kc harmonic outputs, for radio frequency measurements, and 10 kc, 1 kc and 0.1 kc for audio frequency measurements. These connections are all mounted on the rear of the assembly.

8-10c. Type 1101-A Piezo-Electric Oscillator—This oscillator operates with a type 1190-A quartz bar, which is mounted in the temperature control unit, located at the left behind the panel. The temperature is controlled by a compensated thermostat circuit and is maintained within 0.01° C for all ordinary ambient temperatures. The oscillator circuit assembly is mounted at the right behind the panel.

8-10d. Specifications—*Frequency Range.* Standard frequencies ranging from one pulse per second to frequencies of several megacycles can be obtained from this equipment.

The output frequencies are as follows: The upper frequency limit depends upon the method used to detect and utilize the harmonics. The values here quoted are easily reached when using the type 1106 frequency transfer units.

From 100-kc multivibrator, 100 kc and its harmonics up to 50 megacycles.

From 10-kc multivibrator, 10 kc and its harmonics up to 10 megacycles.

From 1-kc multivibrator, 1 kc and its harmonics in the audio-frequency range.

From 100-cycle multivibrator, 100 cycles and its harmonics in the lower audio range.

From the synchronometer unit, one-second contactor. The time of occurrence of the contact may be phased to occur at any instant over a range of one second.

If a suitable high-frequency receiver is used to detect them, 100-kc harmonics up to 75 or more megacycles can be utilized directly. For work at higher frequencies, harmonics of an auxiliary oscillator whose fundamental is monitored against the standard at a lower frequency can be used.

Output Voltage. The harmonic outputs of the 100 and 10 kc are at low impedance (65 ohms). The rms voltages, measured at the terminals of the frequency standard, across a 65-ohm load, are: at 100 kc, 0.2 volt; and 10 kc, 1.2 volts. The audio-frequency outputs are at low impedance (600 ohms). The rms voltages measured at the terminal strip of the standard, across a 10,000-ohm load, are: 10 kc, 20 volts; 1 kc, 25 volts; 100 cycles, 20 volts. These voltages are representative only; they are not guaranteed values.

Frequency Adjustment. The frequency of the quartz bar in its oscillator circuit is adjusted to within 1 part in ten million of its specified frequency in terms of standard time. Slight changes in frequency may occur during shipment but a control is provided for adjusting the frequency after installation.

Accuracy. When the assembly is operated in accordance with instructions, and after an aging period of a month, the rate of drift of the frequency will remain below 5 parts in 10^8 per day and this will decrease with time to about 0.5 part in 10^8 per day at the end of one year's operation.

Frequency Stability. The standard is designed so that ordinary changes in air pressure, ambient temperature, and line voltage have practically no effect on the frequency. The temperature coefficient of frequency of the quartz bar is less than 1 part in 10^7 per degree C. The temperature control is within ± 0.01° C. The voltage coefficient of frequency of the crystal-controlled oscillator is approximately 2 parts in 10^8 for line voltage changes of 10 percent. The average frequency variation from this cause will be substantially less.

The fluctuations of frequency of the standard over short periods, such as those required in making frequency measurements are less than 1 part in 10^9.

8–11. General Radio Type 1105-A Frequency Measuring Equipment—The type 1105-A frequency measuring equipment includes all the auxiliary equipment necessary for measuring unknown frequencies in terms of the type 1100-A frequency standards. When this assembly is used in conjunction with either model of the type 1100-A frequency standard, measurements can be made directly at frequencies up to 100 mc. Measurements at higher frequencies can be made by using auxiliary equipment, such as receivers or oscillators, to transfer the unknown in harmonic steps to a frequency below 100 mc.

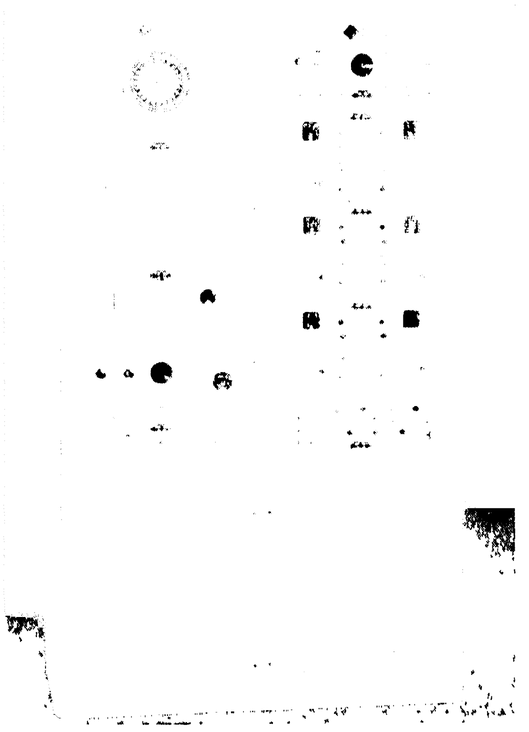

Fig. 8–16. View of General Radio 1105-A frequency measuring equipment with type 1100-AP primary frequency standard.

The general method of measurement is outlined in the diagram Figure 8–17. At radio frequencies between about 100 kc and 100 mc, the unknown frequency is brought into the measuring system through the detector section of a frequency transfer unit or through an external radio receiver. The direct-reading scale of the frequency transfer unit gives the approximate value of the unknown frequency. For a precise determination, the beat frequency between the unknown and a standard frequency harmonic is measured by comparison with the interpolation oscillator, the comparison being made on the oscilloscope.

Above 100 mc, external frequency meters such as the type 720-A can be used to establish a harmonic relation between the unknown and the standard frequency. Other types of stable oscillators can also be used for this purpose.

At audio frequencies, the interpolation oscillator is matched directly to the unknown frequency. A harmonic of the unknown can be used at low audio and sub-audible frequencies.

Between about 5 kc and 100 kc, the interpolation oscillator is used to produce a variable frequency circular sweep on the oscilloscope. The unknown frequency is then determined from the oscilloscope pattern.

The accuracy of measurement that can be easily realized is ± 0.1 cycle in determining the difference between unknown and standard frequencies. The fractional accuracy varies with the frequency being measured ranging from 2 in 10^5 at low frequencies to 1 in 10^8 at high frequencies.

By reversing the procedure of measurement, a precisely known frequency of any value between 100 kc and 200 mc can be generated. The desired frequency is available at the output terminals of a frequency transfer unit. At audio frequencies, from the interpolation oscillator, audio frequencies between 0 and 5000 cycles are available.

8–11a. Type 1106 Frequency Transfer Units—The type 1106 frequency transfer units are utilized in transferring an unknown frequency for measurement against a frequency standard, or for transferring a frequency of known value (determined against the standard) to an output circuit. The direct-reading frequency calibrations will give the approximate value of an unknown frequency, or the approximate value of a desired frequency in the output circuit.

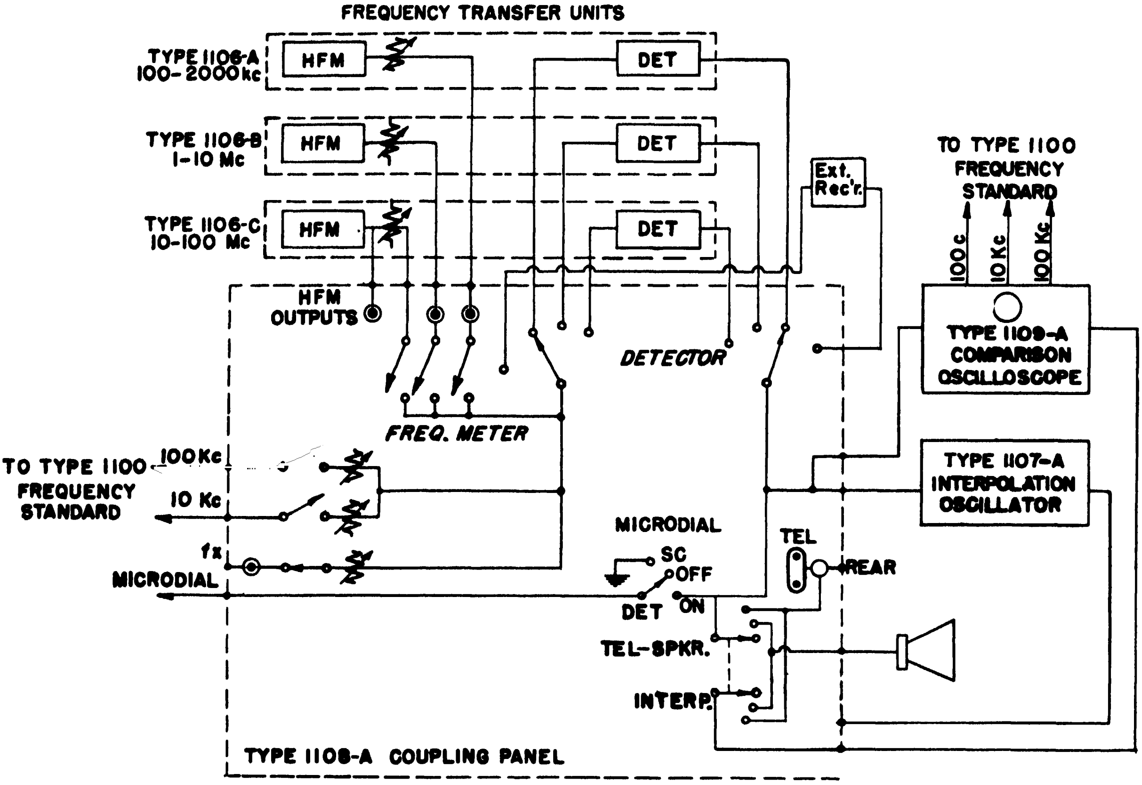

Fig. 8–17. This diagram shows in functional form the operation of the type 1105 frequency measuring assembly. The type 1108 coupling panel is the central unit from which all operations are controlled. The unknown frequency f_x and a series of standard frequency harmonics are applied through attenuators to the heterodyne detector. The unknown can then be estimated quickly from the calibration of the detector, or be determined more accurately by use of the heterodyne frequency meter, or be measured precisely by use of the interpolation oscillator.

When used with a frequency standard, these units provide means for rapidly identifying the harmonics of the standard; for accurately matching the heterodyne frequency meter to the unknown frequency; for use as a substitute source in measuring frequencies under conditions of noise, fading or of intermittent operation of the transmitter; and for obtaining a frequency of any desired value, accurately known in terms of the frequency standard. These instruments can also be used as general purpose calibrated frequency meters and detectors.

The types 1106-A, 1106-B and 1106-C frequency transfer units are identical except for their frequency ranges which are:

Type 1106-A............	100 kc to 2000 kc
Type 1106-B............	1 mc to 10 mc
Type 1106-C............	10 mc to 100 mc

Each consists of a heterodyne frequency meter (with harmonic generating circuits and output control) and a heterodyne detector (with audio-frequency amplifier and regeneration control).

The heterodyne frequency meter oscillator circuit is a highly stable oscillator having a frequency range of 2 to 1 in two (1106-A) or three steps (1106-B, -C). A direct-reading frequency scale is provided for the fundamental and selected harmonic ranges, covering 10 to 1 in frequency (20 to 1 on 1106-A). The harmonic output can be used at frequencies higher than those covered on the dial ranges; for example, using the fundamental frequency scales and reading ten times the scale value gives the coverage of the tenth harmonic.

The heterodyne detector has range-switching and direct-reading frequency scales covering the rated range of the unit. The detector can be operated either in the non-oscillating or oscillating condition by use of the regeneration control. When oscillating, it is especially useful in obtaining an exact zero beat setting between the frequency meter and a signal frequency, by the three-oscillator method, the detector serving as the third oscillator. When not oscillating, it produces the beat between the standard harmonic and the unknown frequency. An audio-frequency amplifier with an output impedance of approximately 600 ohms is provided.

8–11b. Type 1107–A Interpolation Oscillator— The principal use of the type 1107–A interpolation oscillator is, in connection with a frequency stand-

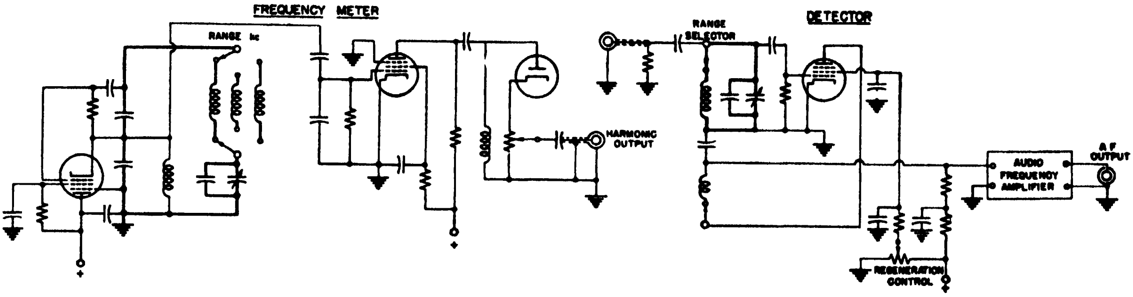

Fig. 8–18. Simplified schematic of the General Radio type 1106 frequency transfer unit.

ard, to measure the difference between the unknown frequency and a known standard harmonic. The direct-reading linear scales of 0 to 5000, and 5000 to 10,000 cycles make possible the rapid evaluation of the frequency difference, by *addition* only, with high accuracy. While the dials are marked as described, the actual frequency range is 0–5000 cycles.

The linear scale of this oscillator also makes it useful for other types of work where accurate frequency increments are desired.

The oscillator is of the beat-frequency type, with the radio-frequency oscillators operating in the region of 45–50 kc. The circuits are designed for exceptional stability of frequency against supply voltage changes, tube capacitance changes and tube replacements. A tube plate-supply regulator is then employed as a further safeguard.

The variable-frequency oscillator frequency is controlled by a precision variable air condenser; the fixed oscillator frequency by a fixed air capacitor. The inductors of both oscillator circuits are wound on ceramic forms and are shielded, effectively eliminating unwanted coupling and reducing the effects of changes in ambient temperature.

An output voltmeter is provided that can also be used as a beat indicator for matching the oscillator output frequency to an unknown audio frequency. Individual controls are provided for the oscillator output and unknown frequency voltages in order to secure the maximum beat amplitude at any level. The oscillator output voltage is practically constant over the whole range of frequency.

The fixed oscillator is provided with a switch which permits changing the frequency exactly 5000 cycles. By thus changing the frequency the oscillator can be fitted with a scale reading 5000–10,000 cycles. When measuring an unknown frequency lying below the standard frequency, the beat frequency need not be subtracted from the standard frequency to obtain the unknown frequency. Instead the 5000–10,000 cycle scale is used and the reading is *added* to the frequency at the next lower standard frequency harmonic.

For measuring very small frequency increments, two direct-reading incremental frequency dials (one for the 0–5000 scale and one for the 5000–10,000 cycle scale) are provided.

8–11c. Type 1108–A Coupling Panel—This coupling panel is designed specifically for use as the centralized control panel in a frequency measuring equipment employing a type 1100–AP primary frequency standard (or type 1100–AQ secondary frequency standard). The panel carries the necessary switches and volume controls for all operations in making frequency measurements.

The instrument contains the following controls: FREQUENCY METER, for selecting and combining the

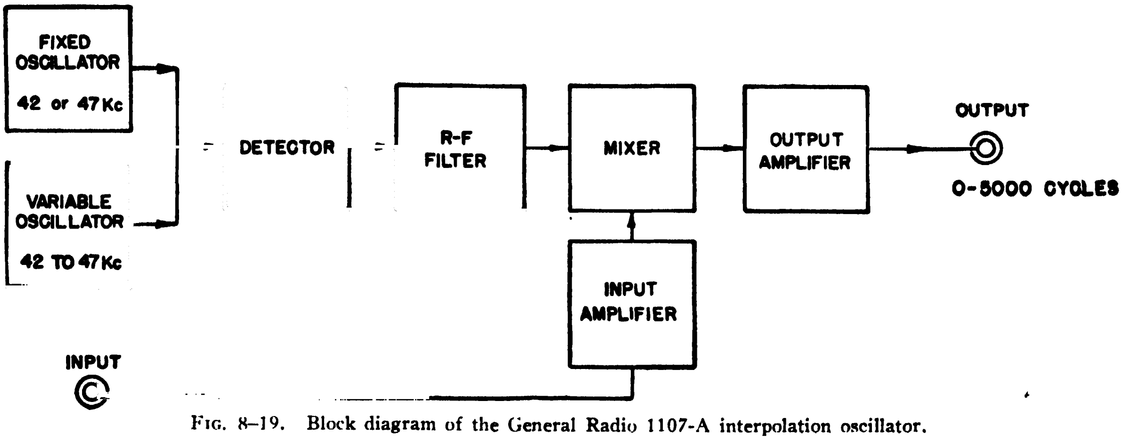

Fig. 8–19. Block diagram of the General Radio 1107-A interpolation oscillator.

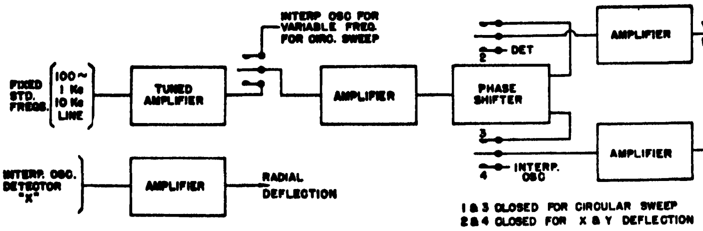

Fig. 8–20. Block schematic diagram of the type 1100-A comparison oscilloscope.

frequency meter outputs of 1106–A, 1106–B and 1106–C heterodyne frequency meter sections; STANDARD FREQUENCY HARMONIC selector, selecting 100-kc or 10-kc harmonic outputs, or combination; individual volume controls; DETECTOR selector, for selecting input and output circuits of 1106–A, 1106–B, 1106–C or an external detector (or receiver); an ON-OFF switch and volume control for frequency being measured; MICRODIAL switch; TEL-SPEAKER switch for transferring between telephones and speaker and between detector and interpolator outputs.

8–11d. Type 1109–A Comparison Oscilloscope—This instrument is particularly intended for use with a type 1100–AP primary frequency standard (or type 1100–AQ secondary frequency standard) as an aid in making interpolations or checking calibrations with high accuracy. With such standards and associated measuring equipment, the type 1109–A comparison oscilloscope provides a convenient means of measuring audio and carrier frequencies, or of calibrating oscillators in these frequency ranges.

The type 1109–A comparison oscilloscope contains a 3-inch, radial deflection cathode-ray tube and its power supply. Selective amplifiers with power supply, phase-shift net-works, and controls are provided for obtaining circular sweeps at frequencies of the power line, and 0.1, 1, and 10 kc from the frequency standard, and at variable frequency obtained from the type 1107–A interpolation oscillator. A radial deflection amplifier is provided, for displaying the input signal on the circular sweep base. Switching is provided for selecting the sweep frequencies and for selecting any one of the several operations normally involved in making frequency measurements or calibrations.

The general use of circular sweeps provides symmetrical and readily interpretable patterns.

By overloading the deflection amplifier it is possible to identify easily frequency ratios involving much higher integers than can be identified in Lissajous patterns.

Ordinarily in the use of calibrated oscillators, it is not necessary to identify a pattern, it is only necessary to adjust the oscillator so that the pattern stands still. A system of known frequencies is easily established on the basis of the *type* of pattern obtained. When used on base frequencies 10 or 100 times higher, *the same types* of pattern correspond to frequencies just 10 or 100 times higher than the original system of known frequencies.

8–12. Microwave Frequency Standard—Figure 8–21 shows a block schematic of the microwave frequency standard used by the Central Radio Propagation Laboratory at the National Bureau of Standards, Washington, D. C. This equipment is employed to generate standard microwave frequencies and to make microwave frequency measurements, tests and calibrations. All frequencies are derived from, or measured directly, in terms of the National primary standard of frequency, the absolute accuracy of which is known at all times to better than 1 part in 100 million. Highly constant oscillators of narrow tuning range are mixed with the multiplied standard frequencies making available an 8-percent bandwidth at output center frequencies of 29.7, 89.1, 267.3 and 801.9 megacycles per second. Harmonics of these output frequencies, generated by silicon-crystal multipliers, give continuous coverage of the range from 342 to somewhat above 30,000 megacycles per second with a known accuracy of 1 part in 10 million or better. In this range a total of over 870 fixed frequencies of approximately 1-percent separation, entirely generated from the primary standard and accurate to 1 part in 100 million, are also made available. Measurements are normally made at controlled temperature and humidity in a shielded room. Absolute accuracy of calibration is usually considerably less than that of the reference frequencies, being limited by the operating band-pass characteristic and dial mechanism for frequency meters, or by the short time frequency changes of oscillators under test.

Detailed descriptions, circuit diagrams and photographs of the individual units will be found in Report CRPL–8–1, 9–4. The following are brief excerpts of interesting features of this equipment.

8–12a. The Frequency Generating Equipment-General Coverage System—

> "The method by which other standard frequencies are derived from the primary frequency standard may be seen by reference to the block diagram in Figure 8–21. The standard frequency, 100 kilocycles per second, is multiplied to a very-high or ultra-high frequency and then impressed across a silicon-crystal rectifier, the harmonics from which are selected to give the desired micro-

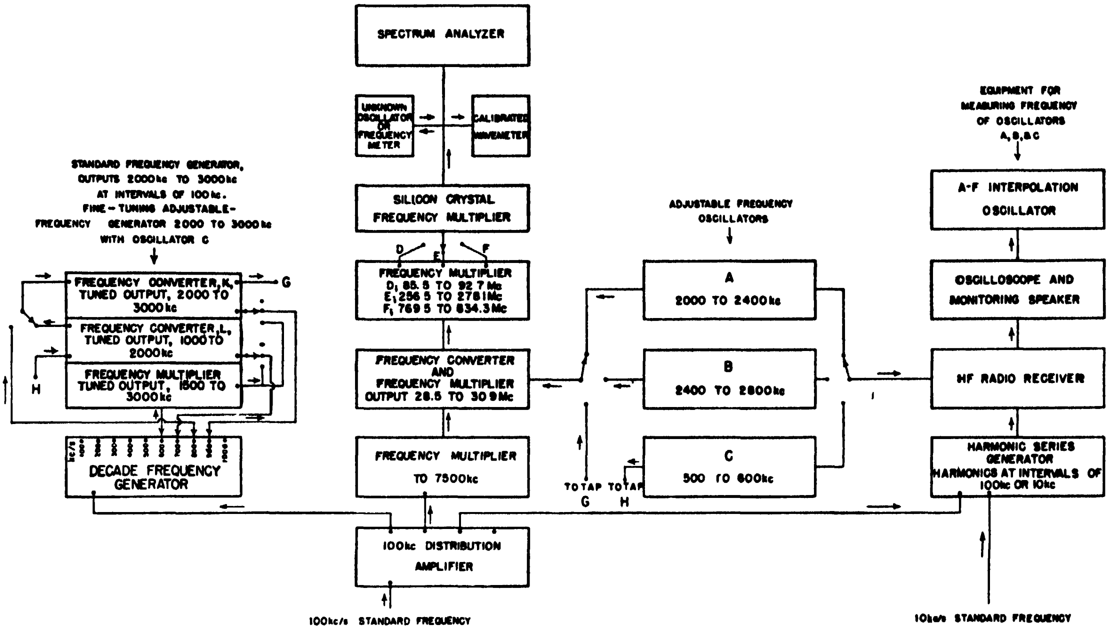
SPECTRUM ANALYZER
UNKNOWN OSCILLATOR OR FREQUENCY METER
CALIBRATED WAVEMETER
SILICON CRYSTAL FREQUENCY MULTIPLIER
D
E
F
FREQUENCY MULTIPLIER D, 85.5 TO 92.7 Mc E, 256.5 TO 278.1 Mc F, 769.5 TO 834.3 Mc
FREQUENCY CONVERTER AND FREQUENCY MULTIPLIER OUTPUT 28.5 TO 30.9 Mc
FREQUENCY MULTIPLIER TO 7500kc
100kc DISTRIBUTION AMPLIFIER
100kc/s STANDARD FREQUENCY
STANDARD FREQUENCY GENERATOR, OUTPUTS 2000kc TO 3000kc AT INTERVALS OF 100kc. FINE-TUNING ADJUSTABLE-FREQUENCY GENERATOR 2000 TO 3000kc WITH OSCILLATOR C
FREQUENCY CONVERTER, K, TUNED OUTPUT, 2000 TO 3000 kc
G
FREQUENCY CONVERTER, L, TUNED OUTPUT, 1000 TO 2000kc
FREQUENCY MULTIPLIER TUNED OUTPUT, 1500 TO 3000kc
H
DECADE FREQUENCY GENERATOR
ADJUSTABLE FREQUENCY OSCILLATORS
A 2000 TO 2400kc
B 2400 TO 2800kc
C 500 TO 600kc
TO TAP G
TO TAP H
EQUIPMENT FOR MEASURING FREQUENCY OF OSCILLATORS A, B, & C
A-F INTERPOLATION OSCILLATOR
OSCILLOSCOPE AND MONITORING SPEAKER
HF RADIO RECEIVER
HARMONIC SERIES GENERATOR HARMONICS AT INTERVALS OF 100kc OR 10kc
10kc/s STANDARD FREQUENCY

FIG. 8–21. Block schematic of microwave standard frequency equipment at National Bureau of Standards.

wave standard frequencies. Continuous coverage is obtained by adding, in a frequency converter, the output of precision, adjustable-frequency oscillators to the output of one of the multipliers and then continuing the multiplication.

"Referring to Figure 8–21 this process may be traced through in detail. The 100 kilocycle per second is first multiplied to 7500 kilocycles per second by conventional multipliers with sufficient filtering to reduce, to a very low value, all spurious side-frequencies and harmonics in the desired output. The resultant frequency is added to the output of oscillator A or B and then tripled to the 28.5 to 30.9 megacycle per second range. Each of the precision oscillators A or B is adjustable over the range shown, with 8000 dial divisions and a very linear scale. After further multiplication, the final frequencies are obtained for application to the crystal-rectifier harmonic generators. The same types of crystals are used in the different ranges of frequencies for harmonic generators as are normally used as mixers or converters in receivers for these same frequency ranges. The frequencies available at points D, E, and F are generated by multipliers using 829B, 832A, and 2C40 tubes, respectively, and giving adjustable output levels as high as 2, 2, and 1 watts. Multiplier circuits are of the ordinary lumped-constant type except for the output circuit of the 270 megacycle per second multiplier which uses parallel lines and the 810 megacycle per second multiplier which uses a butterfly circuit.

"It is seen that about 25 percent of the frequency stability of the output is derived from oscillators A and B, while 75 percent is derived from the primary frequency standard. However, the instantaneous frequency of A or B may be determined by means of the usual calibrating equipment shown to the right in the block diagram. This equipment also serves to monitor the frequency of oscillator A or B if it is desired to maintain a given frequency over a period of time."

8–12b. Crystal Multipliers—The use of silicon-crystal rectifiers of the series 1N21, 1N23, 1N26, or other types to generate high harmonics from the standard frequency outputs at 30, 90, 270, and 810 megacycles per second simplifies considerably the measurement of microwave frequencies. These rectifiers, however, have certain limitations which must be considered when used in this manner.

Since the power output on any particular harmonic is very low (the order of microwatts), it is necessary to work the crystal rectifier at very nearly the maximum power input it will stand under continuous operation. This power is of the order of 0.1 to 0.5 watt, depending on the type and condition of the crystal being used. Crystal input impedances generally range from 100 to 500 ohms.

8–12c. Spectrum Analyzers—Spectrum analyzers of several types are available, but all are essentially high-gain receivers of the "panoramic" type with cathode-ray tubes as indicators. The local oscillator is frequency modulated by a sawtooth frequency in synchronism with the sweep frequency of the oscillator tube, allowing one to observe the response of signals within the range covered. As no image rejection is employed ahead of the crystal frequency converter, an indication will appear when the local oscillator is either lower or higher than the received signal by an amount equal to the intermediate amplifier frequency. Most of the analyzers may be adjusted from zero sweep width to a value wide enough to show both responses as the local oscillator is swept. Provision is also made, through a video amplifier driven by rectified converter-crystal current variations, for observing the "mode" adjustments or sweep range of the

Fig. 8–22. Spectrum analyzer, frequency meters, and crystal multiplier 8500 to 10,000 mc.

klystron local oscillator. By matching pips on this curve, an approximate calibration of frequency meters may be made.

8–13. Frequency Monitors for Standard Broadcast Stations—The remainder of this chapter is devoted to descriptions of commercially available frequency monitors of the type employed by broadcast stations in the standard broadcast band. The rules and regulations of the F.C.C. require that the licensee of each standard broadcast station shall have in operation at the transmitter a frequency monitor independent of the frequency control of the transmitter. This frequency monitor shall be approved by the F.C.C. and must have a stability and accuracy of at least five parts per million.

The frequency monitors described on the following pages meet all F.C.C requirements. The description of these instruments has, for the most part, been taken from the instructions and other literature supplied by the manufacturer.

8–14. General Radio Type 1181-A Frequency-Deviation Monitor—The General Radio type 1181-A frequency-deviation monitor has been designed for use by broadcasting stations operating in the 500 to 2000 kc frequency band to enable them to comply with the frequency tolerance specifications of the F.C.C. and of similar commissions in other countries. This monitor reads frequency deviations directly in cycles and meets the specifications of the F.C.C. for broadcast frequency monitors.

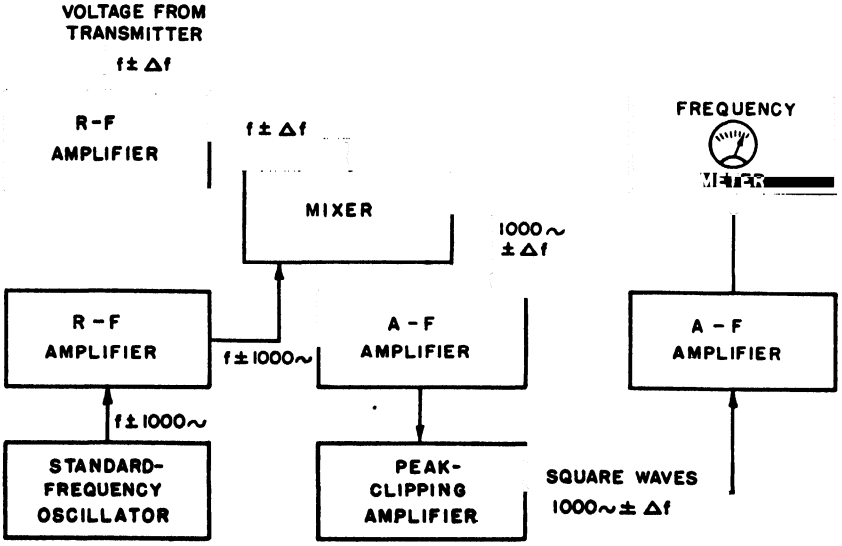

Fig. 8–23. Functional block diagram of the General Radio type 1181-A frequency deviation monitor.

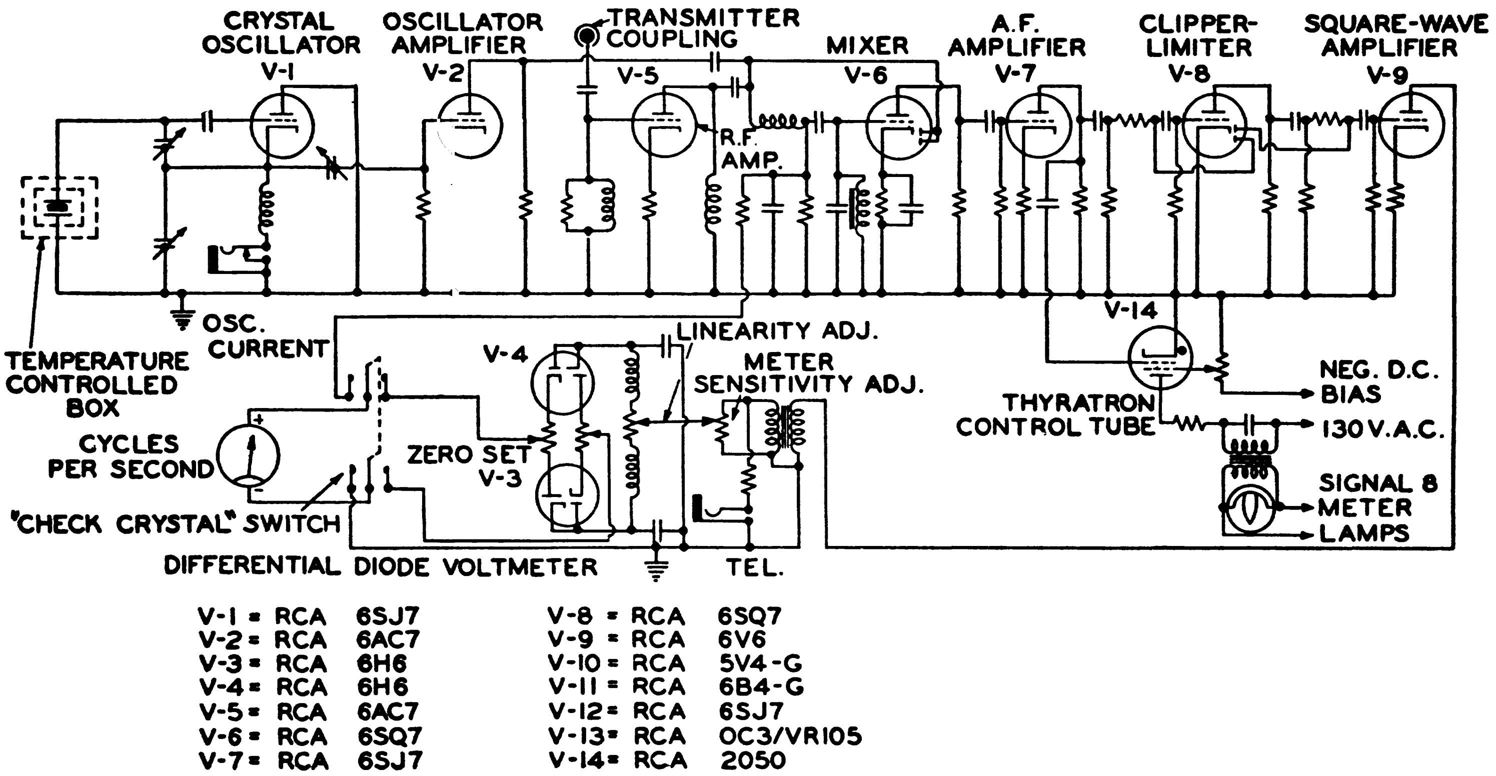

FIG. 8–24. Elementary schematic diagram of the General Radio type 1181-A frequency deviation monitor.

8–14a. Principle of Operation—A functional block diagram of the type 1181–A frequency-deviation monitor is shown in Fig. 8–23. The standard of frequency against which the transmitter is monitored is a piezo-electric oscillator whose frequency differs from the assigned channel frequency of the transmitter by exactly 1000 cycles per second. A voltage derived from this oscillator and a voltage of the transmitter carrier frequency are applied to a vacuum-tube detector where the difference frequency (1000 cycles plus or minus the deviation of the transmitter) is produced. This audio frequency is then amplified and passed through a clipper stage to produce a square wave of constant peak-to-peak amplitude.

The square wave is then fed to a frequency meter which reads zero (mid-scale) when the beat frequency is exactly 1000 cycles. It indicates the deviation from 1000 cycles over a range of ± 30 cycles. It is calibrated to read directly in cycles deviation.

The voltage from the transmitter can be either modulated or unmodulated, since modulation will have no effect upon the operation of the instrument. Consequently, it is not necessary to couple the monitor to the crystal buffer stage. The monitor input is obtained from the modulated transmitter output, and the r-f power required to operate the monitor is so small that only a simple pick-up antenna is needed; usually a few inches of wire is adequate.

8–14b. Circuit Details—An elementary schematic diagram of the type 1181–A frequency-deviation monitor is shown in Figure 8–24. The type 376–L quartz plate used in this monitor has a low temperature coefficient of frequency (less than 3 parts per million per degree centigrade over the normal operating range). The plate is mounted in a dust-proof, air-gap type holder which imposes very little restraint upon its vibration. This assembly is mounted in a temperature-controlled chamber operating at 60° C and is thermostatically controlled.

The crystal-controlled oscillator is of a type developed in the General Radio laboratories specifically for use in standard frequency oscillators where a high degree of stability and reliability are required. It differs from older types of crystal oscillators in that no inductance coil is used in the frequency-determining system. The crystal operates much nearer to its true resonant frequency than is possible in older circuits, and consequently much better stability is obtained.

A jack is mounted on the panel to provide a means of inserting a milliammeter to check the plate current of the oscillator tube.

An r-f amplifier which increases the input sensitivity couples the transmitter input to the mixer and detector and also acts as a buffer amplifier.

The diode detector followed by a stage of audio-frequency amplification is used to produce a beat note resulting from the difference in frequency between the monitoring oscillator frequency and the transmitter frequency. The operating conditions are given in the following table:

Crystal Frequency	Transmitter Deviation	Audio Beat Produced	Meter Reads†
Low Side* of Carrier or f_0-1000	−30	970	−30
	−20	980	−20
	0	1000	0
	+20	1020	+20
	+30	1030	+30
High Side of Carrier or f_0+1000	−30	1030	−30
	−20	1020	−20
	0	1000	0
	+20	980	+20
	+30	970	+30

* This is the general case.

† Polarity of d-c indicating meter arranged at factory to give proper direction to meter reading.

To check the amplitude of the monitoring-oscillator output voltage, the diode detector current is indicated on the panel meter when the CRYSTAL CHECK switch is depressed. A reading above the red line on the meter scale indicates normal operation. The plate circuit of the carrier-frequency buffer amplifier is opened by the action of this switch.

A duplex diode-triode is used as a clipper and limiting amplifier to produce a square wave of constant peak-to-peak amplitude from the audio-frequency signal.

The presence of an audio signal is indicated by a SIGNAL pilot lamp on the panel, and also by the illumination of the meter. A thyratron tube is used for control, and will cause these lamps to glow at normal brilliance when a signal is present and exceeds a predetermined minimum amplitude. When no signal is present, but the circuit is otherwise operating properly, the lamps will glow very dimly.

The square-wave voltage is applied to a power amplifier, the output of which is coupled to the meter circuit by a transformer.

The meter circuit consists of a full-wave differential diode voltmeter, which indicates the potential difference between the midpoints of two series resonant circuits. Circuit constants are such as to cause equal potentials to exist at exactly 1000 cycles, since the two circuits are resonant, one above, and the other below, this frequency. Any deviation from this frequency will cause the current through the meter to assume a direction and amplitude directly proportional to the direction and magnitude of the frequency change, over the normal range of ± 30 cycles deviation.

Internal voltage regulators permit stable operation over a wide range in supply-line voltages, and remove effects due to voltage transients.

8–14c. Specifications

1. *Frequency range.* ± 30 cycles.
2. *Accuracy.* When received, ± 10 parts in 10^6; adjustments are provided to bring the reading into agreement with monitoring station measurements.
3. *Frequency stability.* ± 1 part in one million.
4. *R-f sensitivity.* 100 millivolts at INPUT terminals.
5. *R-f input.* May be modulated or unmodulated.
6. *Input circuit.* High-impedance input circuit. Short, single-wire antenna is adequate for most installations.
7. *Power supply.* 105 to 125 or 210 to 250 volts, 50 to 60 cps.
8. *Power input.* 125 watts, maximum.
9. *Dimensions.* 19 inches wide by 15¾ inches high by 12 inches deep.

8–14d. Installation

1. *Mounting.* The type 1181-A frequency-deviation monitor is designed for mounting in a standard 19-inch relay rack. The relay rack should be grounded; if no rack is used, the monitor should be grounded. The "G" binding post of the R-F INPUT can be used for grounding the instrument.

Do not mount the monitor in relay racks or cabinet racks above power rectifiers or other equipment generating large amounts of heat. Improper functioning of the temperature-control system will result.

2. *Quartz Plate.* The quartz plate is shipped in place in the temperature-controlled heater box and should be ready for operation when the instrument is received. To check whether the quartz plate is properly plugged into the jack mountings in the heater box, remove the wooden cover of the heater box at the rear of the instrument by pulling the spring cover clamps upward. Then open the cover of the inner aluminum case which is held by two slotted thumb screws, one on each side.

3. *Thermometer, Thermostat, and Tubes.* The thermometer is packed separately in the rear compartment of the instrument and should be unpacked carefully and placed in the thermometer hole behind the window on the front panel.

All tubes and the thermostat are shipped in place so it is only necessary to check that they are properly seated in their sockets.

4. *Coupling to Transmitter.* Coupling to the transmitter need not be very close. A very short single-wire antenna in the room should pick up sufficient signal with which to operate the monitor. About 100 millivolts is required. The antenna is connected to the ungrounded R-F INPUT terminal at the left rear of the instrument. The standard R.M.A. monitoring-output connection can be used on transmitters so equipped.

8–14e. Operation

1. *Temperature Control.* Throw the POWER switch ON and the MONITOR switch to OFF. The red HEAT bull's-eye should light immediately, as well as the red one at the lower right of the panel.

To test the operation of the heat-control circuit, short-circuit the thermostat temporarily. The relay should open and the red HEAT lamp go out. A fusible link is provided which melts and opens the heater circuit if the temperature becomes excessively high due to relay or thermostat failure.

The heat will remain on for about a half an hour before the thermostat begins to operate. After about an hour, the thermostat will cycle so that the heat is on (indicator lamp lighted) about 50 seconds and heat off (indicator lamp out) about 160 seconds at ordinary room temperature (70° to 80° F). A period of about four hours is required before the inner temperature reaches its final value. When proper operating temperature has been reached, the thermometer should read 60.0 ± 0.3° C.

2. *Crystal Oscillator.* Adjust the screw on meter case until the meter reads zero. Throw the MONITOR switch ON and allow about a minute for the tube to stabilize. Depress the CHECK CRYSTAL button to the right of the meter on the panel. A deflection of the meter to the right indicates that the crystal is oscillating. This deflection should be at least to the red line at 15 on the meter.

A jack, engraved OSC. CURRENT, is provided at the lower left-hand corner of the panel. A 0–25 ma d-c meter plugged into this jack will indicate the anode current of the crystal oscillator. The meter will read between 6 and 9 ma when the crystal is oscillating and approximately 15 ma when the crystal is not oscillating.

3. *Input Signal Level.* The red SIGNAL pilot lamp and the illuminating lamps are connected in the same circuit and the meter should be at full brilliance. If they are very dim or flicker badly, insufficient signal is being picked up from the transmitter. About 100 millivolts at the input terminals will be sufficient for proper operation. The instrument will operate properly over a range of 0.1 to 25 volts carrier input. If single-frequency modulation at multiples of 60 cycles is used, the lamps may flicker at a low frequency because the modulation frequency is beating with the power-line frequency. Normal program modulation will not cause the lamps to flicker, unless the carrier input signal is too low.

4. *Meter Reading and Transmitter Deviation.* If the transmitter frequency is within ± 30 cycles of its assigned value, the meter will indicate the frequency deviation in cycles per second. Should the transmitter be more than ± 30 cycles and less than about ± 360 cycles off frequency, the meter pointer will be off scale. If the station is more than ± 360 cycles off the assigned frequency, the meter may read on scale, but the indication will be false. *The station should be adjusted as closely as possible before using the deviation meter.* Should there be any doubt as to whether or not the station is ap-

proximately correct, i.e. within 30 cycles, plug a pair of phones into the jack marked TEL. on the right of the panel. The tone heard should be 1000 ± 30 cycles. This may be checked against a 1000-cycle tuning fork or a calibrated audio oscillator.

A ZERO SET adjustment is provided under a snap button on the panel located near the meter. By means of this adjustment the point of zero frequency deviation, as indicated by the meter, can be changed. Slight differences between operating and calibrating temperatures, rough handling in shipment, or slight aging effects may shift the operating frequency of the quartz crystal in the monitoring oscillator. The ZERO SET permits the operator to bring the indication into exact agreement with measurements made by government or commercial monitoring stations.

Example: Suppose the average of a number of measurements indicates that the station frequency is 10 cycles high. The ZERO SET is adjusted until the meter reads + 10 cycles high, which makes the monitor agree exactly with the measurements. If the monitor is then left alone, and the station frequency adjusted until the deviation meter reads zero, the station will be exactly on frequency as determined by the agency making the measurements.

5. *Stand By.* When the transmitter is not operating, the frequency monitor should be turned off by throwing the MONITOR switch to OFF. This will allow the tube circuits to be shut off without disturbing the operation of the heat-control system on the crystal oscillator. The switch marked POWER controls the entire instrument and should not be used unless the unit is to be taken out of operation for an extended period.

8–14f. Tube Replacements—The following tubes may be replaced without affecting the over-all performance of the instrument in any way.

V–1	RCA Type 6SJ7
V–2	RCA Type 6AC7
V–5	RCA Type 6AC7
V–6	RCA Type 6SQ7
V–7	RCA Type 6SJ7
V–10	RCA Type 5V4–G
V–11	RCA Type 6B4–G
V–12	RCA Type 6SJ7
V–13	RCA Type 0C3/VR105

V–3 and V–4 can be replaced without producing a serious error, but some selection is desirable for the best results, as follows:

(a) Remove the rear Jones plug from the EXT. METER receptacle at the rear of the monitor.

(b) Set the mechanical zero adjustment on the meter.

(c) Remove the connections to the r-f input and short circuit these terminals.

(d) Replace the Jones plug and adjust the ZERO SET control on the panel. If the ZERO SET control has been previously used to compensate for a frequency drift in the crystal frequency, note the original reading before replacing the tubes, and then set to the same value when setting the ZERO SET control.

If V–8 (6SQ7) or V–9 (6V6) are replaced, the electrical meter circuits may be affected somewhat. The maximum errors encountered by direct tube substitution will not exceed ± 8 percent of the indicated reading, or ± 6 percent of the indicated reading, respectively. These are *maximum* possible variations. It is good practice to replace the tubes with tubes of the same manufacturer as are originally supplied with the instrument. This will minimize the possibilities of introducing errors.

When replacing V–14 (2050), the operation of the SIGNAL lamp circuits should be checked. This

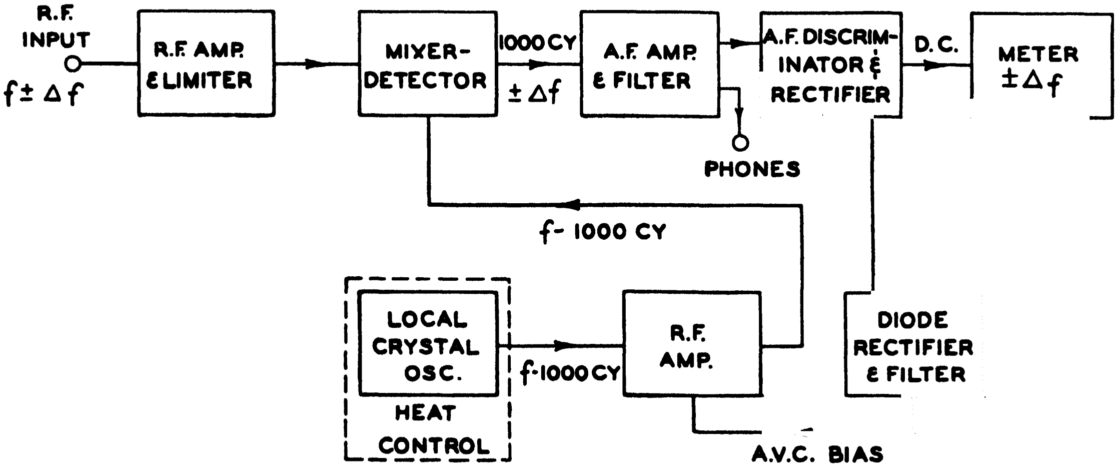

FIG. 8–25. Block diagram of the RCA type 311-AB broadcast frequency monitor.

may be done by removing the r-f input and shorting the INPUT terminals. Adjust the V-14 bias potentiometer *clockwise* until the SIGNAL pilot lamp attains full brilliance; then slowly rotate this potentiometer counterclockwise until it appears to go out. Leave the potentiometer set at this position.

8-14g. Vacuum Tube Data—There is given in the following table a listing of tube voltages measured from socket pins to ground using a 20,000 ohm-per-volt test meter. These measurements were made with the monitor operating normally at a line voltage of 115 volts, 60 cps with no r-f signal applied. The d-c voltages, except as noted might vary ± 20 percent from the values shown.

Symbol	Type	Socket Pin Number						Description
		2	3	4	5	6	8	
V-1	6SJ7	6.5(AC)				165	250	Crystal Oscillator
V-2	6AC7	6.5(AC)			2.2	165	280	Oscillator Amplifier
V-3 (See note 1)	6H6	6.5(AC)						Voltmeter Diode
V-4 (See note 1)	6H6	6.5(AC)						Voltmeter Diode
V-5	6AC7	6.4(AC)			1.6	55	300	R-F Amplifier
V-6	6SQ7					195	6.4(AC)	Mixer
V-7	6SJ7	6.4(AC)	0.3	{0.10 (+gnd)}	0 3	47	185	A-F Amplifier
V-8 (See note 2)	6SQ7					165	6.4(AC)	Clipper-Limiter
V-9	6V6	6.5(AC)	250	230		250	16.0	Square-Wave Amplifier
V-10	5V4G	{2 to 8 5 (AC)}		370(AC)		370(AC)	415	Rectifier
V-11	6B4G	{2 to 7 6.3(AC) 255}	420		222			Regulator
V-12	6SJ7	{2 to 7 5.3(AC)}	106	105	106	125	222	Regulator
V-13	0C3/VR105				106			Regulator
V-14	2050	6.0(AC)	95(AC)			6.9		Thyratron Control Tube

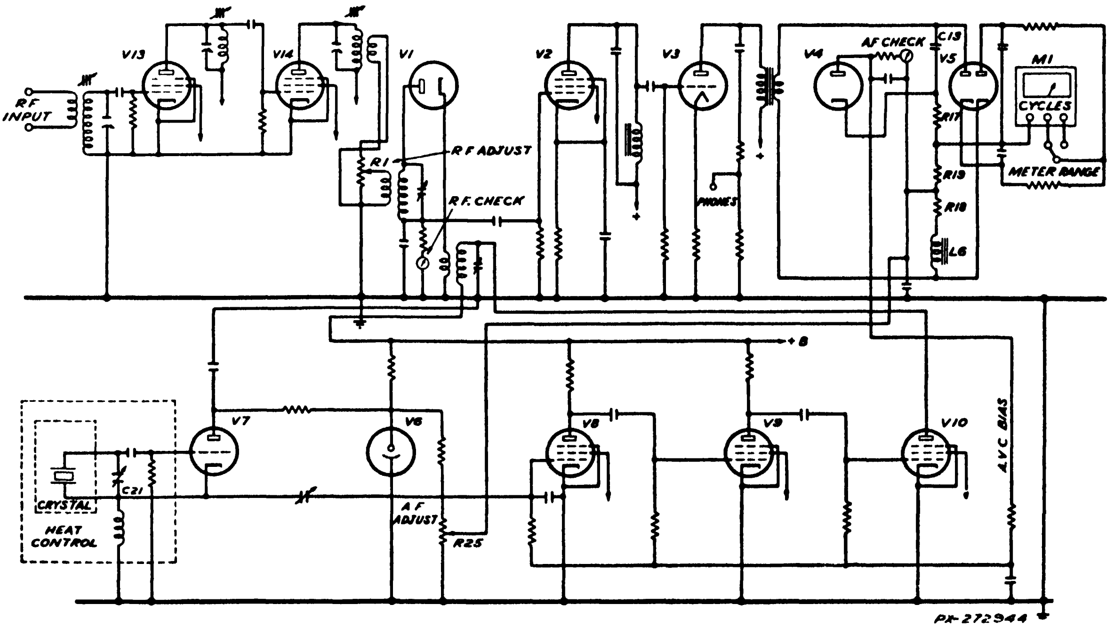

FIG. 8-26. Simplified schematic diagram of the RCA type 311-AB broadcast frequency monitor.

Note 1. When the meter reads zero with the monitor operating and regardless of whether or not a signal is applied, there are no voltage readings obtainable except those of the filaments. However a continuity and resistance check between some of the socket terminals of V–3 and V–4 will ordinarily indicate defective components in that part of the circuit. The normal resistance values are given in the following table.

From Terminal	Tube	To Terminal	Tube	Ohms
3	V-3	4	V-4	330
5	V-3	8	V-4	0.1 Meg
3	V-3	6	V-3	47
6	V-4	4	V-4	74
4	V-3	3	V-4	0.1 Meg

Note 2. The small values of voltages indicated are difficult to measure accurately. The following lists the resistance from some of the socket terminals of V–8 to ground.

Terminal	Ohms
2	2 Meg
3	0
4	0.12 Meg
5	0.3 Meg
6	0.5 Meg

8–15. RCA Type 311-AB Broadcast Frequency Monitor—The type 311-AB broadcast frequency monitor provides continuous indication of the deviation of a broadcast transmitter from its assigned frequency. It was designed to meet the specifications of the Federal Communications Commission, as set forth in Rule 3.60 and described in Section 15 of "Standards of Good Engineering Practice."

The electrical characteristics of the type 311–AB broadcast frequency monitor follow:

Radio-frequency range	540–2,000 kc
Frequency deviation ranges	± 20 and ± 100 cycles
Range of off-scale indication	From −100 to −500 cycles and +100 to +1,200 cycles, on ±100 cycle range
R-f input voltage	1 to 4 volts (approx. 100-ohm input)
Power supply	105–125 volts, 50–60 cycles
Power consumption (continuous)	100 watts
Additional consumption of oscillator heater	70 watts intermittent
Accuracy:	
Oscillator frequency stability	± 2 parts per million

Changes of ± 20% of the r-f input level will produce less than one cycle variation.

Change of oscillator frequency with a ± 5% line voltage variation and 25° C ambient temperature variation 0.5 parts per million (total).

Approximate maximum change of deviation indication, in the audio system, due to a ± 5% line voltage variation and a 25° C ambient temperature variation as follows:

1.2 cycles (total) near zero deviation.
1.7 cycles (total) at 100 cycles deviation.

The principle of operation is indicated by the block diagram of Figure 8–25 and is shown more completely by the simplified schematic diagram of Figure 8–26 and the complete schematic of Figure 8–27. It may be described briefly as follows:

Local oscillator signal from V–7, controlled as to amplitude by the AVC bias on the oscillator amplifier (V–8, 9 and 10), is supplied to the detector (V–1) as the smaller of the two r-f components. The other component, a carrier signal obtained from a buffer stage of the transmitter, and amplitude-limited by V–13 and V–14, is adjusted to have an amplitude, at the detector (V–1), of approximately fifteen times that of the local oscillator signal. This adjustment, which involves the transmitter coupling and the R. F. CHECK switch, is fully explained under "Installation." The two components combine to produce a beat tone.

The function of the amplitude-limiter or "Clipper" amplifier, V–13 and V–14, is to remove any program modulation which may be present in the signal from a buffer stage and which might otherwise result in undesirable fluctuation of the indicating meter due to certain audio components disturbing the metering circuit.

The local oscillator frequency is approximately 1,000 cycles below the transmitter carrier frequency, producing a detector output with a frequency equal to this difference. This output passes through an r-f filter network to a broadly tuned 1,000-cycle-amplifier stage (V–2). This stage serves both to reduce distortion errors (due to hum modulation on the carrier, oscillator wave-form, etc.) and to feed an a-f power stage (V–3). The latter is transformer-coupled to the series *R*, *L* and *C* circuit of the discriminator (C–13, R–17, R–18, R–19 and L–6).

The inductive and capacitative elements of this circuit (including some series resistance), across which are connected the two discriminator diodes (V–5), are adjusted to have numerically equal impedances at a frequency very close to 1000 cycles. It is evident that, for this audio frequency, the two diode currents will cancel in the CYCLES meter (M–1) and produce no deflection.

When the transmitter carrier deviates from its assigned value, producing an a-f above or below 1000 cycles, different voltages will be supplied to the two diodes (V–5), resulting in an unbalance current in the CYCLES meter (M–1). The latter is a zero-center instrument, and is calibrated in cycles HIGH or LOW from assigned carrier frequency.

In order to obtain satisfactory scale spread on the CYCLES meter, and to hold the deviation calibration, it is necessary to maintain constant current in the

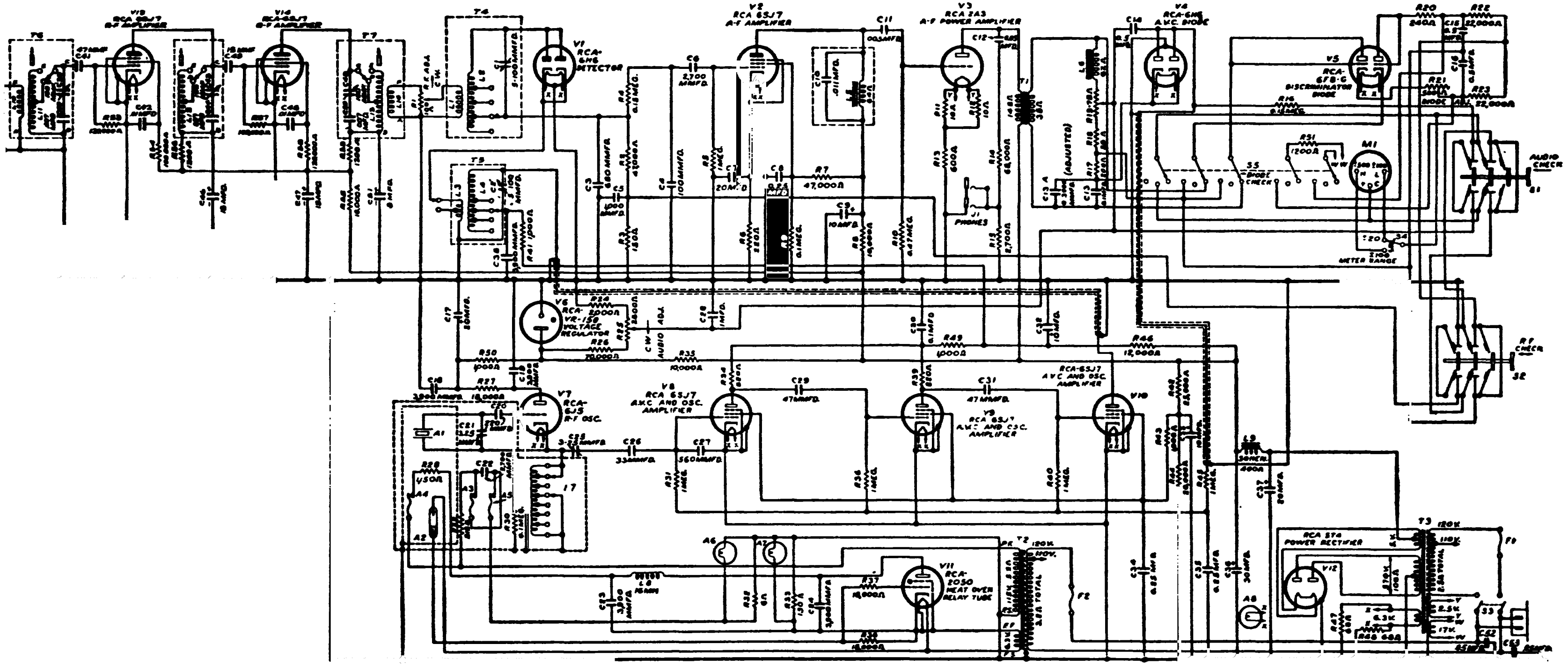

Fig. 8–27. Schematic circuit diagram of the RCA type 311-AB broadcast frequency monitor.

R, *L* and *C* discriminator circuit. The AVC circuit, obtaining voltage from the resistive elements (R–17, R–18 and R–19) of this discriminator circuit, controls the amplitude of the local oscillator signal at the detector (and thus the a-f amplitude) so as to maintain substantially constant current in the discriminator circuit over the deviation range. A manual control (R–25), in the bias circuit, is also provided for resetting this a-f level for accurate readings of deviation.

The crystal oscillator is adjusted, at the factory, to a frequency 1000 cycles below the transmitter's assignment. After installation, however, a transmitter frequency check should be obtained and the trimmer (C–21) on the monitor oscillator adjusted so that the meter indicates the measured deviation. When the transmitter is exactly on frequency, the a-f beat tone will then be within several cycles of 1000 cycles, and the meter will indicate zero deviation.

The crystal for the local oscillator is mounted in a special type holder which tends to minimize the effects of jar and vibration. This is mounted in a double heat box, which practically eliminates the effects of normal ambient temperature variations. The inner box is controlled by a low-differential mercury thermostat (A–2), and the relay tube V–11. The outer box, which also contains the remaining oscillator-circuit components (except the tube), is controlled by a bi-metal thermostat (A–3) of high sensitivity. A–4 and A–5 are bi-metal safety cutouts which open the heater circuits if, for any reason, the box temperatures should exceed their normal values appreciably.

Operation of the AUDIO CHECK switch (S–1) places M–1 in series with the load resistor (R–16) of diode V–4, thus indicating the a-f current amplitude in R–17, 18 and 19—or in the discriminator circuit. The tap on R–19 is so adjusted, at the factory, that true off-frequency indication, on the CYCLES scale of M–1, will result if the AUDIO CHECK operation produces the specified a-f level indication, as marked on M–1.

The approximate level at which the AVC holds the 1000-cycle audio current in the discriminator circuit is adjustable by means of R_{25} (AUDIO ADJ.), which alters the amount of fixed positive bias (which is "bucked" by the negative AVC bias from V–4) on the r-f amplifier. This, in turn, alters the amount of audio current required to produce (in V–4) the negative bias necessary to bring the AVC circuit to equilibrium; thus serving as a control on the audio level. Since the AVC action is not perfect, it is necessary, in making an accurate deviation reading, to check the audio level and adjust to the proper indication on M–1.

The DIODE CHECK switch, S–5, is provided for occasional checks on matching of the dynamic resistances of the discriminator diodes (V–5) around their operating point. This operation makes a bridge circuit of the two diodes and their load impedances; with 60-cycle voltage across one diagonal (of proper amplitude to produce normal peak current in the diodes), and M–1 across the other diagonal. The diodes are then effectively balanced by setting R–21 (DIODE ADJ.) for zero deflection of M–1. S–5 momentarily shorts M–1 during the switching operation.

All controls and check devices which are normally used, in obtaining a deviation reading, are located on the front panel. These include the power switch (S–3), the meter range switch (S–4) (± 20 and ± 100 cycles), and three push buttons which indicate, by deflection to certain markings on M–1, the following: S–2, the existence of proper r-f input level; S–1, correct level of a-f beat signal in the discriminator circuit; and S–5, correct adjustment of the DIODE ADJ. control (R–21) in the discriminator diode circuit. Also on the front panel are the indicating meter (M–1), a circuit-power pilot lamp (A–8), pilots A–6 and A–7 showing heater operation on the outer and inner crystal-oscillator ovens respectively, and a thermometer showing the temperature of the crystal chamber.

In order to prevent erroneous indication due to accidental disturbance of adjustment settings, the diode balance control (R–21) and the a-f level control (R–25) are placed on a sub-panel, which is accessible through a small door in the front panel. Also on this sub-panel are r-f input control (R–1) (which is not a critical adjustment), and a telephone jack (J–1) for monitoring the audio tone. The oscillator frequency adjustment, the small trimmer condenser C–21, is located in the outer heater oven, and can be adjusted, by means of a bakelite tuning tool, after removing a plug button in the rear cover of the oven.

The small trimmer C–25, located at the rear of the small, top chassis, is an adjustment of oscillator voltage supplied to the r-f amplifier. It is properly adjusted at the factory and, since its setting has an appreciable effect on oscillator frequency, should not be disturbed; except, perhaps, in a service operation which will be followed immediately by a check from a frequency service. This precaution also applies to all other components in the oscillator circuit.

The transformers in the r-f input amplifier (L–10, L–11, L–12, L–13, L–14, L–1, L–2) and the oscillator-amplifier output transformer (L–3 and L–4) are provided with taps which are used, in conjunction with C–1, C–2, C–39, C–43, C–49 to cover different parts of the r-f frequency range of the monitor. The oscillator cathode coil (L–7) is provided with similar taps. The ranges of these adjustments are outlined under "Maintenance and Service," but all of these circuits are adjusted, at the factory, at the particular frequency for which each monitor is ordered.

The filter comprised of L-8, C-23 and C-24 serves to eliminate r-f noise generated in the heater-relay tube, V-11.

The two power transformers, T-2 and T-3, are each provided with two primary taps to permit operation over the line voltage ranges of 105-115 and 115-125 volts. Separate fuses, F-1 and F-2, are provided for circuit power and crystal-oven power.

8-15a. Installation—The monitor is designed for mounting in a standard 19-inch rack. The dust cover is notched, near the bottom of the side edges (which fit against the panel), in order that the power cord and r-f input line may be permanently attached and passed through these notches; thus providing no interference to removal of the dust cover.

A power supply of 105 to 125 volts (preferably subject to less than several volts variation), 50-60 cycles, capable of delivering 175 watts, is required. The power transformers, T-2 and T-3, are wired at the factory, for 115-125-volt operation. If the supply voltage does not exceed 115 volts, the power input circuit should be changed to the 110-volt tap on the base of each of these transformers.

The monitor is unaffected by field strengths which would normally exist in an equipment rack. However, it is recommended that it be placed outside the immediate fields of high-power r-f stages or high-power rectifiers.

The crystal unit (A-1), mercury thermostat (A-2) and thermometer, which are separately packed, should not be installed until the unit is mounted in the rack and the following operations are completed.

R-f signal to the input binding posts must be obtained from an unmodulated buffer or intermediate stage which has adequate power to permit the absorption of about 0.02 watts. Inductive or capacitative feed may be employed, preferably through a 70-ohm concentric line, to the r-f input terminals on the rear apron. If a monitor terminal is not provided on the transmitter, a coil of several turns and a diameter of several inches, loosely coupled to a suitable tank circuit, should provide adequate signal strength. A high voltage condenser of about 100 $\mu\mu$f connected to one or more turns above r-f ground on a suitable tank coil should also suffice. The concentric line preferably should not be grounded except at its ends, and should be kept away from lines carrying modulated r-f.

In adjusting the r-f input system, see that the crystal unit is not connected, remove fuse F-2 from its mounting on the rear apron of the chassis. Set the meter RANGE switch to ± 20, the R. F. ADJ. to near mid-position, and turn on the POWER switch. Put the transmitter into operation. Modulator and final-stage power are, of course, unnecessary. Now push button A (S-2) under the meter, and vary the transmitter coupling or signal voltage by adjusting the pick-up coil or condenser. Observe that the meter reading is practically constant over a wide range of input voltage, due to the action of the limiter stages. Decrease the input voltage to zero, and then increase it to a value slightly above the point at which the R. F. CHECK reading fails to increase appreciably with increasing input. If an r-f voltmeter is available, simply set the input between 1 and 2 volts. ***In no case should the input voltage exceed 4 volts.*** Now, with button A again depressed, set the R. F. ADJ. so that the meter deflects within the red R. F. CHECK region.

After turning off the circuit power, the crystal unit should be installed in the inner box of the heat oven. Care should be taken that the contact clips, and leads from the crystal to the outer heat box, are well spaced from each other and from the box surfaces. The "high" terminal of the crystal (the one nearest the top, or name-plate, of the unit) must be connected to the stator of trimmer C-21. See that the lid of the inner box is securely fastened by its four screws.

The mercury thermostat should now be placed in its three retaining clips, which are under, and at the left side of, the heavy, inner crystal box. The two thermostat leads must be secured to the two screw terminals near the lower right-hand corner of the inner crystal box, and the spare length pushed beneath this box. See that the oven doors are closed securely.

Remove the small CRYSTAL TEMP. bezel from the front panel and carefully insert the thermometer, pushing the graduated leg into its slot. No appreciable force should be required.

Replace the fuse in the rear apron of the chassis (momentarily disconnecting the power cord). Put the dust cover in place—with the power cord and, if possible, the r-f input line, dressed to come out through the notches in its side edges, against the front panel. If the r-f line is a heavy concentric cable, it may be necessary to run it to the input terminals through the hole in the back of the cover; and disconnect it each time the cover is removed.

With the power switch in the "OFF" position, both of the heater pilots should light within 30 seconds after plugging in the power cord. Place the meter range switch on "± 100," and turn the power switch to the "ON" position. The power pilot should light, and shortly the meter will deflect—probably showing nearly full scale frequency error, because of the crystal being far below its normal operating temperature. After about 10 minutes' warm-up, press button B, turn the range switch to "± 20," and set the DIODE ADJ. control for meter deflection to DIODE CHECK (mid-scale). Press button C (with range switch on "± 20"), and set the AUDIO ADJ. control for meter deflection to the AUDIO CHECK mark.

The monitor should now be left, with all power on, for a period of at least 24 hours before any final adjustments are made. This is advisable, not only in order that the crystal and ovens may reach constant temperature, but also to allow all other parts of the equipment to reach a stable operating condition after shipment and installation. After several hours the oven heater pilots will start going out intermittently and the thermometer columns will come into view.

After this stabilization period, the oven heater power should be left on continuously, circuit power only being interrupted by the monitor power switch. Hence the monitor should be connected to an outlet from which the power cannot be cut off.

Before the monitor may be used for frequency logging it must be adjusted finally against a transmitter check from a reliable frequency service. Have the monitor power turned on for at least a half hour before the check, and see that it reads very close to zero deviation on the ± 20-cycle scale. This adjustment is made by varying the crystal trimmer capacitor in the outer crystal oven; which is reached by removing a plug button in the oven door and using a low-capacity tuning tool which will fit the small slot on the trimmer. Also make certain that the R. F. ADJ., DIODE ADJ. and AUDIO ADJ. controls are reset to give proper meter indications as previously outlined—pressing buttons A, B and C, with the RANGE switch on "± 20." The DIODE CHECK and AUDIO CHECK readings should be exactly on the line. Also make a record of the "crystal temperature" thermometer reading, which should remain stable hereafter.

At the pre-arranged time for the frequency measurement, take the deviation reading of the monitor, and, in order to minimize drift errors, get the check result and make final adjustment as soon as possible. Having received the measurement result, determine the monitor error; or find by how much the monitor was reading too high or too low at that time. Now re-check the three ADJ. controls, as previously explained, for a possible new deviation reading. Then adjust the crystal trimmer condenser, as previously explained, so as to change this reading by the proper amount and direction to correct for the measured indication error. If the change is more than a few cycles, the AUDIO ADJ. should be rechecked as this new reading is approached.

As an example of the foregoing, assume the following conditions: At the time of the measurement, the monitor read 1 cycle high. The frequency report showed that the transmitter was 5 cycles high; which means that the monitor read 4 cycles too low. Therefore, set the crystal trimmer on the monitor for a deviation reading of 5 cycles high, thus correcting its 4-cycle error. Then adjust the transmitter for a reading of zero deviation.

The monitor will now be ready for routine operation as described in the following section.

8-15b. Operation—After proper installation and calibration, according to the foregoing instructions, the following operating procedure should be observed.

Turn the power switch on at least 15 minutes before the carrier is to be measured. (The frequency can be measured, of course, before power is applied to the final transmitter r-f stages.) Before taking an accurate frequency reading, the following checks should always be made: (a) see that the crystal temperature is at its stable value; (b) with the meter range switch on "± 20," press buttons A, B and C for checks on r-f level, diode balance adjustment and audio level, making any change required on the three ADJ. controls to give the exact meter readings. The meter will now indicate true deviation in cycles, on either frequency scale.

The R. F. ADJ. control should require very little resetting, but should always be checked to see that the deflection is within the red region. The DIODE ADJ. and AUDIO ADJ. controls may require slight readjustment at each reading.

It is recommended that the crystal oscillator of the transmitter be retrimmed, as necessary, to keep deviation indication within several cycles. If frequent, large readjustments in frequency should become necessary at any time, or if a sudden jump of more than the tolerance limit should occur, an investigation of the cause should be made at once. In such situations, there are three possible causes of the trouble: (a) the transmitter has changed frequency; (b) the monitor oscillator has changed frequency; (c) the audio indicating system of the monitor is defective. Of the first two, (a) is the more probable cause, since the monitor crystal works at a very much lower power level than the crystal in a transmitter exciter, and has received special precautions for stability. Trouble (c) is probably not present if the DIODE and AUDIO checks can be made, but it can be detected by listening to the tone from the monitor phone jack and matching it with tone from an audio oscillator which has a good frequency calibration (or by checking against any good audio reference frequency, such as a tuning fork). If the monitor tone is within a few cycles of 1000, and the cycles meter shows deviation outside of tolerance, then the trouble is in the audio system of the monitor. (Possible causes may be found by standard test methods and reference to "Maintenance" and the schematic and wiring diagrams herewith.) If the monitor tone appears to agree with the deviation indication, or if no external reference frequency is available, then the transmitter tuning should be changed, if possible, to give zero deviation indication (on the strength of the probability between causes (a) and (b)), and a frequency measurement should be obtained at once.

If the monitor should read within tolerance and, at the same time, it should be impossible to set the AUDIO ADJ. control properly, the audio indicating system can again be checked by comparing the tone to a good reference frequency.

Actual false indication, with all adjustments being normal, is possible only when the transmitter is between 1900 and 2100 cycles low. This can be checked by slightly raising the transmitter frequency. If the transmitter is low by the above amount, this change will produce a deflection toward "low" deviation. For normal conditions, it should result in deflection toward "high."

Periodic checks of tubes and other maintenance precautions are recommended, as outlined in the following section. Certain precautions outlined therein with regard to changing tubes should be noted particularly, since V-3, V-4, V-5 and V-7 may have appreciable effect on deviation indication. Periodic frequency measurements, by a reliable service as required by the Federal Communications Commission, are necessary.

8-15c. Maintenance—Circuit adjustments, other than those described under "Operation," should not be required. The oscillator circuit should not be disturbed except in the case of failure, and any readjustments should be followed by a frequency measurement. The principles of operation of the monitor have already been outlined and should be evident from the simplified and complete schematic diagrams. Checks for localizing the cause of excessive deviation indication are outlined under "Operation." If the monitor should become defective, it should be possible to locate the failing component, by standard test methods, using the accompanying tube voltage data, and wiring and schematic diagrams.

For power line voltages between 105 and 115, connect to the 110-volt taps on the primaries of T-2 and T-3. For voltages between 115 and 125, connect to the 120-volt taps.

Under normal operating conditions, the following approximate values of signal voltages should occur on the circuit elements as listed:

V-1 cathode, 0.75 volt osc. signal. (With normal carrier input. Several volts with no carrier.)
V-2 grid, 0.25 volt, 1000 cycles.
V-3 grid, 26 volts, 1000 cycles (use tube voltmeter).
V-3 cathode, 10 volts, 1000 cycles.
V-3 plate, 49 volts, 1000 cycles.
Across T-1 secondary, 19.5 volts, 1000 cycles.
V-4 plate to cathode, 8.2 volts, 1000 cycles.
Across L-6, R-19 and R-18 (in series), 44 volts, 1000 cycles.
Across C-13 and R-17, 47 volts, 1000 cycles.
V-8 grid, 0.3 volt r-f (approx. for normal carrier input).
V-9 grid, 0.25 volt r-f (approx. for normal carrier input).
V-10 grid, 0.2 volt r-f (approx. for normal carrier input).

The small variable condenser C-25 on the rear of the top chassis is set at the factory for proper oscillator voltage to the grid of V-8. Since this setting has a slight effect on oscillator frequency, *C-25 should not be disturbed except in a major servicing operation which will be followed by a frequency check.* With normal r-f input signal, proper "Audio Check" indication and normal gain in the oscillator amplifier system, proper setting of C-25 is indicated by approximately — 3.5 volts d.c. on the

D.C. VOLTAGES TO CHASSIS*

Tube	Cathode	Grid	Screen	Plate
6H6-V-1	0	—	—	−15 (at R-2, with normal r-f signal)
6SJ7-V-2	1.5	0	87	210
2A3-V-3	38	0	—	255
6H6-V-4	6	—	—	-4 (with normal r-f signal)
6F8G-V-5	KT2, 62 KT1, 6	GT2, 6 GT1, −50	-	PT2, 6 PT1, −50 (with normal r-f signal)
VR150-V-6	0	—	—	150
6J5-V-7	0	−3	—	85 (approx. oscillating value)
6SJ7-V-8	0	−3.5 −0.5†	95 60†	170 90†
6SJ7-V-9	0	−3.5 −0.5†	95 60†	170 90†
6SJ7-V-10	0	−3.5 −0.5†	90 60†	180 90†
2050-V-11	0.5	—	—	−45 (conducting)
5T4-V-12	310		—	0
6SJ7-V-13	0	−0.5†	40†	120†
6SJ7-V-14	0	−0.5†	40†	120†

KT1—KT2
GT1—GT2 Tube Elements
PT1—PT2

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* Tube voltage data (at rated line voltage). The above are approximate operating voltages. The use of an ordinary low-resistance voltmeter for measurements will lower some of the above values appreciably, as may be inferred from the schematic diagram.

† With no r-f signal.

plate of V–4 (measured with an instrument of at least 50,000 ohms resistance). This will correspond to approximately 0.3-volt oscillator signal on the grid of V–8.

It is advisable that all tubes in the monitor should be tested periodically. Changing of tubes V–3, V–4, V–5, and V–7 may have some effect on a-f indication, but the indicated frequency should not change appreciably over the useful life of a given tube or set of tubes. The possible error resulting from these changes may be outlined as follows:

Change of oscillator frequency due to changing oscillator tube, approximate maximum of 3 parts per million (total).

Approximate maximum change of deviation indication, in the audio system, due to tube changes are given as follows:

Tube	Total Cycle Variation
A–F Power Amplifier	1
A–F Discriminator Diode	3
AVC Diode	1 cycle near zero deviation 3 cycles near 100-cycle deviation

It is therefore advisable that these four tubes particularly should be checked periodically and changed before they drop below about 80 percent of normal rating, and that such changes should be made immediately before obtaining a periodic frequency check. If the carrier frequency has shown very good stability, these tubes may be changed with reasonable safety by noting the change in indicated frequency resulting from the tube change, and trimming the monitor oscillator to correct for this possible change of several cycles. (Always check the settings of controls A, B and C, and allow sufficient time for warm-up.) In the event of an emergency change following failure of one of these four tubes, the same procedure can be followed by referring to the station frequency log; *provided* that the log and observations indicate that the carrier frequency has been quite stable. This, however, is not as safe as direct observation of indication change.

Condenser C–10 and inductor L–5 are adjusted at the factory and mounted in a single unit, and cannot be replaced individually. These components resonate at approximately 1000 cycles, and the gain of the V–2 stage is consequently peaked at this frequency. Measuring the voltage on C–11 with a tube voltmeter, the gain of this stage at 500 cycles and 2000 cycles should be approximately 20 percent of that at 1000 cycles.

Inductor L–6 and condensers C–13 and C–13A are also adjusted at the factory to give zero indication at 1000 cycles. In the event of trouble with any of these units, it would be necessary to return the complete instrument to the factory for readjustment, or to make the replacement according to the following procedure: If C–13A (this may be two molded condensers in parallel) only should fail, note the values stamped thereon and order corresponding units. C–13 and L–6 are stocked in matched pairs. If either one of these should fail, both must be replaced; and a new value of C–13A will very probably be required, making it necessary to order all four of the units. After installation of L–6 and C–13, connect a source of 1000-cycle signal (which should be accurate within about one cycle, and should contain not more than about one percent distortion) to the grid of V–2. Adjust the amplitude of this source until the monitor meter reads on the red "Audio Check" line (with range switch on "± 20") when button C is pressed. Now select a value of C–13A which will make the meter indicate within one cycle of zero deviation. This may require a selected pair of the four molded condensers to be used in parallel. This procedure should result in an indication with an accuracy of several cycles, but an early frequency check would be advisable.

Any servicing which requires removal from the rack or handling of the monitor should be followed by a stabilizing period of about 8 hours' operation (more if the crystal oven is cold) before making a deviation adjustment against a frequency check. The complete set-up procedure and adjustments are outlined under "Installation."

The oscillator cathode coil L–7 and the r-f coils L–2, L–3, L–4, L–11, L–12 and L–13 are adjusted at the factory for the operating frequency specified. In the event that these adjustments should be changed or the monitor used on a new frequency, the data on tuning ranges of the various taps, given in the following table, will be useful. The r-f tuning condensers are located in the tops of the individual coil cans, and can be reached by means of a bakelite-rod tuning tool. L–11, L–12, and L–13 also may be tuned by means of their adjustable magnetite cores. The terminals referred to appear below the chassis, on the lower ends of the coil forms. Tuning can be accomplished by means of the "R. F. Check" procedure, and adjusting for maximum indication. It is necessary to tune with reduced r-f input voltage, however, in order to prevent masking of the tuning by the AVC action of the "Clipper" amplifier. With the R. F. ADJ. at about ⅔ maximum and the meter on ± 20 range, the input voltage should be set, in each tuning operation, to produce a maximum deflection of about 4 on the ± 20 scale.

Make the connections and adjustments indicated in the table above for the desired frequency. Remove the oscillator tube (V–7) and tune L–2 first. Then tune L–13, L–12, and L–11 in this order, reducing the input in each case as explained above. For the last two adjustments it may be necessary, in order to get sufficiently low input, to disconnect the r-f line from the monitor and use a short piece of wire as an antenna on the R. F. terminal. Now remove all r-f input signal from the monitor, replace the oscillator tube and tune L–4 for maximum meter deflection, which may be only several scale divisions.

Tuning Ranges of R-F Coils

Range in kc	Terminal or Jumper Connections and Tuning Ranges of R-F Coils						
	R-F Ampl. Coil		Clipper Ampl. Coils		Osc. Coupl. Coils		
	L-2		*L*-11, 12 and 13		*L*-3	*L*-4	
	Jumper from:	Jumper from:	Jumper from:	Core. turns "in" from max. "out" position	Jumper from:	Jumper from:	Jumper from:
540– 750	1 to A	—	C to E	7	3 to E	1 to A	—
750–1100	1 to B	—	C to E	7	3 to H	1 to B	—
1100–1550	1 to C	—	C to D	4	3 to H	1 to C	—
1550–2000	1 to D	A to B	C to D	4	3 to E	1 to D	A to B

This procedure completes tuning of the r-f amplifiers, and has no effect on oscillator frequency. The input voltage should be set as explained in the section *Installation*. For making a change in oscillator frequency, the procedure for setting C–21 and C–25 is given earlier in this section. The oscillator cathode coil (located in the outer heat oven) is not tuned, but in order to obtain a strong crystal fundamental component, a tap is selected which is resonant within about 20 percent of the crystal frequency. The accompanying list of jumper connections in the following table is in the order of increasing resonant frequency, and shows approximate crystal frequencies for various connections.

Oscillator Coil Connections

Jumper Connections		Approx. Crystal Freq.
1 to:	8 to:	
open	open	
2	open	
3	open	540
4	open	
open	7	600
5	open	
2	7	
3	7	
open	6	800
6	open	
4	7	900
2	6	
open	5	1000
3	6	
2	5	
open	4	1500
3	5	
2	4	
open	3	2000

The lowest frequency coil which will give stable oscillation should be used. The procedure for final adjustment of C–21 and C–25 is given in an early part of this section.

The schematic diagram clearly indicates the operation of the oven heater circuits. The inner oven should regulate at approximately 70° C, and show practically no variation. The outer oven should regulate at approximately 65° C. Although it should require no attention, a screw adjustment is provided in the tubular thermostat in the outer oven.

The operation of the various switching circuits should be apparent from the schematic diagram. It should be stated, however, that the "Diode Check" switch (S–5) creates a bridge circuit of the two diodes in V–5 and their load resistors and condensers, with a 60-cycle voltage across one diagonal and the meter across the other. This produces peak diode currents of the same order as those produced by signal, and R–21 is then adjusted for balance as indicated by the meter.

8–16. Western Electric 1A and 1C Frequency Monitoring Unit—There follows a description of the Western Electric 1A frequency monitoring unit which was designed for insuring the maintenance of a broadcast station carrier frequency within the tolerance prescribed by the F.C.C. The 1A was originally designed when the 50-cycle tolerance was in force and subsequently when the tolerance was reduced to 20 cycles the Western Electric Company furnished instructions whereby the equipment could be converted to meet this new standard. The description that follows includes the 1A and information for converting this unit to the 1C frequency monitoring unit.

The No. 1A frequency monitoring unit provides a means for checking the operating frequency of a radio broadcasting station by comparing the frequency of the transmitter with that of a stable crystal-controlled oscillator. This reference oscillator is an integral part of the monitoring unit and is accurately adjusted to the assigned frequency of the station. In addition to the crystal-controlled oscillator, the monitoring unit contains temperature control equipment for the oscillator, two screen-grid radio frequency amplifiers, a detector, a visual frequency difference indicator, and complete power equipment. The power equipment is arranged for operation from a 110-volt, 50- to 60-cycle a-c power supply. The unit can be modified for operation from a 220-volt, 50- to 60-cycle power source.

The radio-frequency voltage to be checked can be obtained from any stage of the radio transmitter, from an antenna near the transmitter, or from a radio receiver tuned to the transmitter frequency.

8–16a. General Description—The principle of operation is as follows: The output of the oscillator in the monitoring unit and the radio frequency voltage from the transmitter are each amplified by one of the two radio frequency amplifiers which are coupled to a detector having a polarized relay in its plate circuit. Since the output of the detector contains a beat frequency equal to the difference between the two radio frequency inputs, the armature of this relay is caused to vibrate, alternately charging a condenser from the plate voltage supply and discharging it through a meter calibrated in cycles per second. The circuit is so arranged that this meter then indicates directly the difference between the frequency of the transmitter and that of the reference oscillator.

The reference oscillator (No. 700A oscillator) is calibrated as a unit to the assigned carrier frequency of the station. A control on the side of the oscillator, which is set at zero on the scale at the time of calibration, permits limited frequency adjustment. The setting of this control should not be changed unless it is desired to make a small frequency adjustment when measurement by a recognized authority indicates the desirability of so doing. The dial has an arbitrary scale for reference purposes and a careful readjustment to zero should restore the original setting of the oscillator frequency.

The quartz crystal in the oscillator is maintained at a constant temperature by a heater supplied with power through a three-element rectifier tube acting as a relay. The grid voltage of this tube is in phase with the plate voltage when the oscillator temperature is low and current flows into the heater. When the crystal temperature reaches the proper value, the contacts of a mercury thermostat close applying an out-of-phase grid voltage to the rectifier tube, preventing the flow of current into the heater.

One transformer supplies the necessary power for the oscillator and amplifier tubes and another supplies the power for the heater control tube. A full-wave rectifier with a suitable filter furnishes the required screen, plate and grid voltages.

8–16b. Installation—The No. 1A frequency monitoring unit can be installed on a desk or table or mounted on a standard rack. For rack mounting the No. D–95314 shelf is used and the assembly requires 15¾ inches of rack space.

When the unit is furnished for operation from a 110-volt, 50- to 60-cycle a-c power supply, the primaries of T1 and T3 are connected in parallel and the resistance of the rheostat R8 is approximately 50 ohms. When furnished for 220-volt, 50- to 60-cycle a-c operation, the primaries of the transformers are connected in series and the resistance of the rheostat R8 is approximately 200 ohms.

Cords terminated in plugs are provided to connect the unit with the a-c power source and the radio frequency input. The power supply cord is furnished with a nonpolarized plug. A standard receptacle that will not accept the polarized radio frequency plug should be used in the power supply outlet. The receptacle for the radio frequency plug should be a General Electric polarity plug receptacle, Graybar Catalog No. GE–996 or a similar outlet. Care should be exercised that the power supply is never connected to the radio frequency input as excess voltage will damage the circuit.

A radio-frequency transmission line from the transmitter to the radio-frequency outlet may be run in conduit or exposed as desired. A single shielded conductor should be used as the transmmision line. The copper shield should be grounded and connected to the wide contacts on the receptacle. This transmission line should be connected to a source of suitable radio-frequency voltage either by direct connection or by use of a coupling coil. This coil may consist of approximately 10 turns of wire on 3-inch diameter tubing. The coupling should be adjusted to provide two volts or more to assure proper operation of the frequency monitoring unit.

When the monitoring unit is installed where the field strength is high, the radio-frequency input may be obtained from a small antenna wired through an opening in the base of the monitoring unit and connected to terminal No. 5. With the unit operating from an antenna, the red bus wire connecting C9 and R17 should be disconnected. To disconnect this lead the front compartment must be opened by removing the screws at the corners of the panel and the knob on the input control.

The No. 1A frequency monitoring unit can be operated at a distance from the radio transmitter in conjunction with a tuned radio frequency type of receiver. When the monitoring unit is operated in this manner, the red wire connecting C9 and R17 should be disconnected, and a lead connected from terminal No. 5 to the grid of the detector tube in the radio receiver. This lead should be as short and direct as possible to prevent detuning of the preceding radio frequency circuit in the receiver.

To place the temperature control circuit in operation place the switch D1, marked PRIMARY, in the ON position. The cathode of the heater relay tube V1 should reach a dull red color in about one minute. After this interval has elapsed, the switch D2, marked PLATE, should be placed in the ON position. When this is done, V1 should glow and the crystal heater indicator lamp E1 should light.

In about one hour the thermostat should reach the operating temperature and the lamp should be automatically extinguished. After this, the lamp should light at intervals of about one minute. A period of three hours should elapse after the temperature control circuit is placed in operation before any frequency readings are taken.

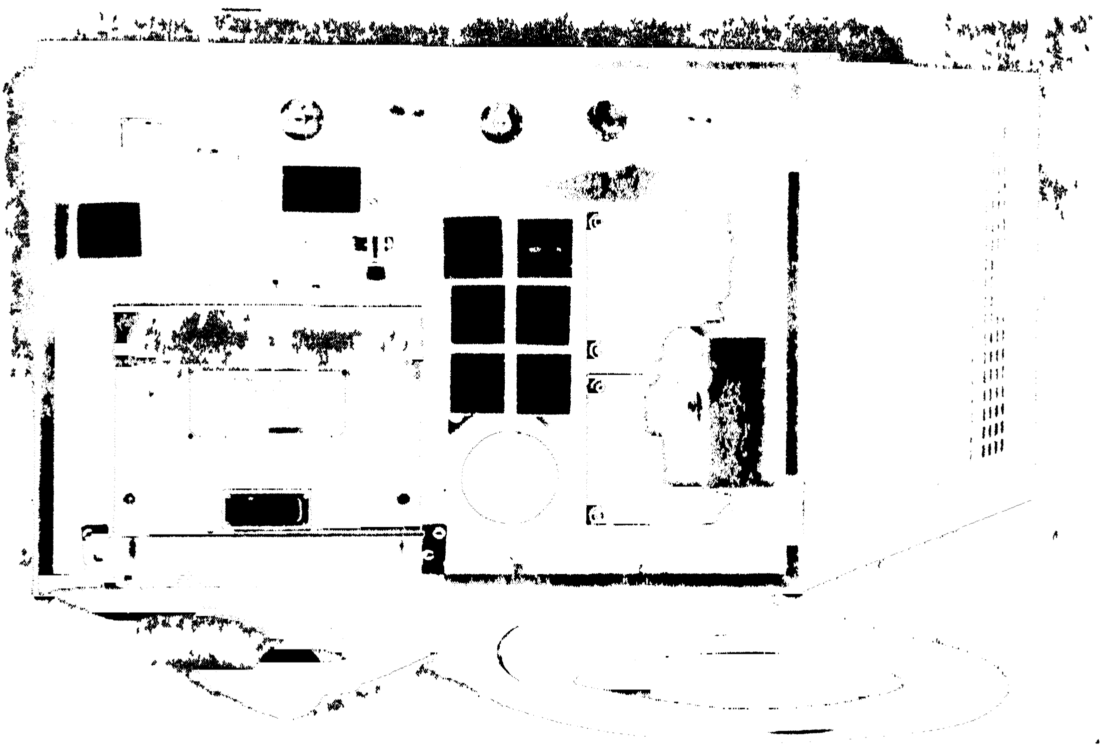

FIG. 8-28 Rear view of the Western Electric 1A frequency monitoring unit showing the 700A oscillator in place. This equipment provides a means for checking the operating frequency of a radio broadcasting station by comparing the frequency of the transmitter with that of a stable crystal-controlled oscillator This reference oscillator is an integral part of the monitoring unit and is accurately adjusted to the assigned frequency of the station.

To operate the unit, place the power switch lever on the front panel in the ON position and allow the tube cathodes to warm up for about one minute. Adjust the control marked VOLTAGE until the OSCILLATOR PLATE VOLTAGE voltmeter indicates 130 volts. The OSCILLATOR GRID CURRENT meter should indicate between 0 05 and 0 8 ma, showing that the oscillator is operating.

With the radio transmitter in operation, press the FREQUENCY DIFFERENCE button and slowly rotate the potentiometer marked INPUT to increase the signal voltage. When sufficient voltage has been applied to the amplifier tube, the frequency difference will be indicated on the meter providing the difference between the frequency of the transmitter and that of the oscillator in the monitoring unit is between zero and 75 cycles

If the input control is set at the maximum position and no frequency difference reading is obtained, press both the FREQUENCY DIFFERENCE and DIRECTION buttons. If an indication has not been obtained previously and the pressing of the DIRECTION button causes the meter to read, the frequency under measurement is exactly the same as that of the No 1A frequency monitoring unit.

Failure to obtain an indication may be due to the difference frequency being too high for the instrument to indicate or on account of insufficient input voltage from the transmitter.

Aural observation of the difference frequency may be made by plugging headphones into the jack provided for that purpose. If the difference frequency is observable but high, the transmitter frequency may be adjusted until the frequency of the sound in the headphones is estimated to be within the range of the frequency difference meter. The headphones should then be removed from the circuit, as they decrease the sensitivity of the frequency difference indicator, and an observation of the meter made by depressing the indicator switch. If it is still impossible to obtain a meter indication, increase the voltage from the transmitter by closer coupling or by lengthening the pick-up antenna as the case may be. When a meter indication is obtained, decrease the input by means of the INPUT control until the point is reached where the relay just ceases to follow. Then increase the input sufficiently to insure steady operation.

8-16c. Measurements—When the monitoring unit has been placed in operation, measurements may be made as follows:

1 Depress the push button marked FREQUENCY DIFFERENCE and observe the reading of the meter marked FREQUENCY DIFFERENCE.

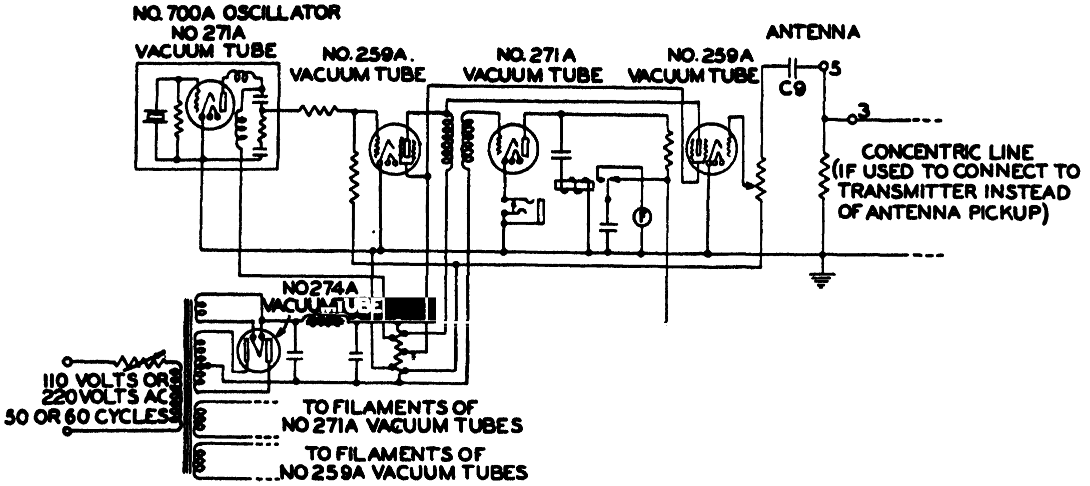
NO. 700A OSCILLATOR
NO 271A VACUUM TUBE
NO. 259A. VACUUM TUBE
NO. 271A VACUUM TUBE
NO. 259A VACUUM TUBE
ANTENNA
C9
5
3
CONCENTRIC LINE (IF USED TO CONNECT TO TRANSMITTER INSTEAD OF ANTENNA PICKUP)
NO 274A VACUUM TUBE
110 VOLTS OR 220 VOLTS AC 50 OR 60 CYCLES
TO FILAMENTS OF NO 271A VACUUM TUBES
TO FILAMENTS OF NO 259A VACUUM TUBES

FIG. 8–29. Simplified schematic of W.E. 1A frequency monitoring unit.

2. With the FREQUENCY DIFFERENCE button operated, depress the DIRECTION button slowly and observe the change in the reading of the FREQUENCY DIFFERENCE meter.

The first operation will give the frequency difference. If the second operation decreases this difference, the transmitter frequency is low. If this operation increases the frequency difference, the transmitter frequency is high.

In using a frequency monitoring unit greater benefit will usually be obtained by periodically reading and recording the frequency difference than by making frequent insignificant adjustments of the transmitter frequency to make it agree with that of the monitoring unit. The statistical records thus obtained will show the normal variations of the system so that steps can be taken to correct the abnormal performance of an individual element before serious trouble develops.

For transmitters having two oscillators, a statistical system may be established by graphically recording at suitable intervals the difference in frequency between the oscillators in the transmitter and the monitoring oscillator. Three curves should be plotted against time as follows:

A. The frequency difference between the monitoring unit and oscillator No. 1 in the transmitter.

B. The frequency difference between the monitoring unit and oscillator No. 2 in the transmitter.

C. The frequency difference between the two oscillators in the transmitter.

The data for C may be obtained by subtracting the values of B from A.

As a single example, assume that the frequency of oscillator No. 1 is 6 cycles higher than the monitoring unit frequency and that the frequency of oscillator No. 2 is 4 cycles lower than that of the monitoring unit. The frequency difference between oscillators No. 1 and No. 2 will then be as follows:

$$C = A - B = (6) - (-4) = 10 \text{ cycles}$$

The subtraction shows that in this particular case the frequency of oscillator No. 1 is 10 cycles higher than that of oscillator No. 2.

If the frequency of one of the three oscillators changes abnormally, the three curves will indicate which oscillator is at fault. If curves A and C begin to change and B remains constant, the frequency of oscillator No. 1 has changed. If curves B and C begin to change and A remains constant, the frequency of oscillator No. 2 has varied.

Graph paper, similar to the No. 4117 made by the Codex Book Co. of Norwood, Mass., will be found satisfactory for plotting the frequency deviations. This paper has arbitrary ordinates which may be marked in cycles and the abscissae are labeled in months of the year.

In the case of a transmitter with only one oscillator, the above statistical method may be applied to a degree by inserting the spare oscillator in the transmitter periodically and checking its frequency after at least three hours' operation.

When the carrier frequency of the transmitter is properly measured and an error in the reference oscillator is indicated, the frequency may be reset by adjusting the control on the monitoring unit oscillator until the FREQUENCY DIFFERENCE meter registers the measured deviation. To make such an adjustment unscrew the plug in the side of the monitoring unit and insert a screw-driver in the slot provided.

After the frequency of the monitoring unit oscillator has been set, the frequency of the oscillator or oscillators in the transmitter may be made to agree with the monitoring unit, thus re-establishing the system.

8-16d. Maintenance—The magnitude of the undertaking in attempting to maintain constantly the frequency of a broadcasting station within 20 cycles of its assigned value must not be underestimated and that the achievement of such operation is largely dependent upon the diligence of the operating staff and upon the care and intelligence with which the station equipment is maintained must be appreciated if success is to be had.

Being precision equipment, the No. 1A frequency monitoring unit should be handled with care and it should be observed at regular intervals to make certain that the operation is normal. While the maintenance is simple, it should be properly attended to in a regular manner.

The oscillator grid current should be observed regularly and if it decreases materially, the oscillator tube should be replaced.

The temperature control circuit will require occasional replacements of the relay tube and indicator lamp which are in service continuously. The use of the relay tube eliminates the hazard of excessive temperatures. However, *on account of the vital function of this tube in maintaining the proper frequency of the oscillator, it is imperative that the tube employed be in operative condition. Normal operation of this tube is indicated by the periodic flashing of the indicating lamp on the front of the unit and any irregularity in the operation of this lamp should be promptly investigated.*

After considerable use the contacts on the relay may accumulate dirt or wear sufficiently to cause erratic readings of the frequency difference meter. In this case the contacts should be cleaned and adjusted. A No. 74D gauge and two No. 340 adjusting keys are furnished for relay adjustment as follows:

The total contact travel, that is, the distance which the armature travels in passing from a position against either contact screw to a position against the opposite contact screw should be 0.004 inch. When the armature is in a position halfway between the pole-pieces, it should not be touching either contact. The No. 4 leaf of the No. 74D gauge is 0.004 inch thick and should be used for gauging the contact travel. The No. 340 adjusting key should be used for adjusting the contacts.

The magnetic air-gap, that is, the clearance between the stop pins on the armature and either pole-piece, with the armature against the opposite pole-piece should be 0.010 inch, which corresponds to leaf number 10 in the No. 74D gauge. If this air-gap is incorrect, the pole-pieces should be readjusted using one No. 340 adjusting key to turn the pole-piece and the other to turn the lock nut.

The monitoring unit should be cleaned periodically with a jet of compressed air or a soft clean rag to prevent the accumulation of dust or dirt.

Note: Before any relay adjustments are made, the power switch on the front panel should be placed in the OFF position.

8-16e. Conversion of 1A Unit to 1C Frequency Monitoring Unit—The 1A frequency monitoring unit may be converted in the field to obtain a precision that will meet the latest standards of good engineering practice concerning broadcast stations by making the changes outlined in the following pages. The following apparatus is required:

1—KS-8433 meter
1—Nameplate per ESA-676779

In addition to the above the following will be required which it is assumed will be supplied by the station:

1—Cathode-ray oscillograph, preferably with input amplifiers, the gain of which may be varied
1—Two-connection telephone plug
A source of 60 cycles a-c, 2 to 6.3 volts

The 1A frequency monitoring unit nameplate is removed by unscrewing the four screws which attach it to the front panel. The 1C frequency monitoring unit nameplate may then be screwed in its place. The KS-7186 deviation indication meter is removed by unscrewing three screws which attach it to the panel and the new meter is screwed in its place. Connections to the new meter are the same as with the old meter.

As received from the manufacturer the 700B or 700C oscillators are calibrated for zero deviation with the carrier frequency of the station, and the frequency control is set on zero. When used in the monitor the control will be offset on the "de-

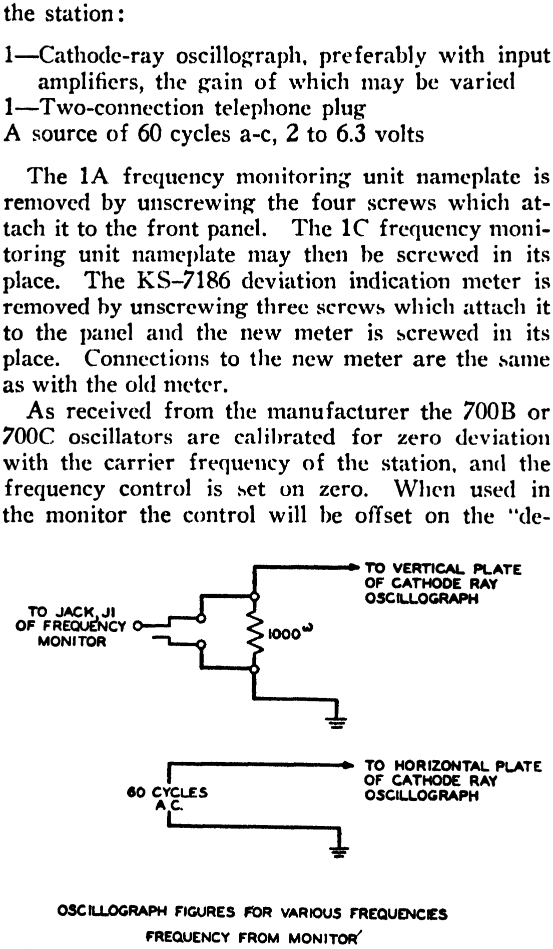
TO VERTICAL PLATE OF CATHODE RAY OSCILLOGRAPH
TO JACK J1 OF FREQUENCY MONITOR
1000ω
TO HORIZONTAL PLATE OF CATHODE RAY OSCILLOGRAPH
60 CYCLES A.C.
OSCILLOGRAPH FIGURES FOR VARIOUS FREQUENCIES
FREQUENCY FROM MONITOR
60 CYCLES
40 CYCLES
30 CYCLES
20 CYCLES
+30
+10
0
-10
DEVIATION METER READING

FIG. 8-30. Instructions for conversion of 1A frequency monitoring unit to 1C frequency monitoring unit.

crease" side of zero to obtain 30 cycles difference between its frequency and the carrier frequency. The new meter should be calibrated as follows:

Connect the cathode-ray oscillograph and associated apparatus as is shown in Figure 8–30.

The monitor should be in normal operating condition and current from the transmitter should be supplied in the manner outlined in the instruction book for the 1A frequency monitoring unit.

1. With switch D4 open, adjust the pointer of the meter by means of the screw on the meter so that it reads — 30 cycles exactly.
2. Vary the frequency of the monitor oscillator in either direction to obtain 60 cycles difference frequency between it and the station carrier frequency by comparison with the 60-cycle supply on the oscillograph.
3. Depress frequency difference switch D4. The meter should read + 30 cycles. If it does not, adjust condenser C7 until it reads + 30 cycles exactly. The approximate capacitance of C7 will be 0.1 μf.
4. Vary the frequency of the oscillator in the monitor to obtain 30 cycles difference frequency on the oscillograph.
5. Depress frequency difference switch D4. The meter should then read zero cycles. If it does not, readjust the pointer of the meter by means of the screw on the meter so that it reads exactly zero cycles. This adjustment may be necessary because the frequency characteristics of the meter may not be exactly linear. If the adjustments are carefully made the meter should read deviations up to ± 20 cycles better than ± 1 cycle. The meter may be checked at other points by varying the frequency of the monitor oscillator to obtain the patterns shown in Figure 8–30. The corresponding meter readings are shown.
6. While the frequency of the monitor may be varied in either direction to calibrate the meter, the monitor must be set after the calibration is finished so that the frequency of its oscillator is — 30 cycles in order that the deviation meter will read direction properly. Check or adjust the position of the deviation pointer on the monitor oscillator so that it is on the "decrease frequency" side of zero. As a further check, by depressing the frequency direction switch C13, the pointer will move to the right.

The calibration of the meter is made by assuming that the transmitter frequency deviation is zero. After the calibration is finished and the transmitter frequency is known to be off frequency by a certain amount, adjust the oscillator in the monitor so that the deviation is that amount. Then adjust the transmitter oscillator so that the deviation is zero.

With the exception of maintaining the monitor oscillator 30 cycles off frequency from the carrier frequency of the transmitter, the operation and maintenance outlined in the 1A frequency monitoring unit instruction book should be followed. The frequency deviation is obtained by closing switch D4. Check the direction of the deviation of the monitor oscillator occasionally by use of the frequency direction switch C13. It should always move to the right.

This completes the conversion for stations using Western Electric 700B or 700C oscillators. If the frequency assignment is changed, however, the oscillator should be returned to the Western Electric Company for replacement of the quartz crystal.

Stations using 700A oscillators should return them to the Western Electric Company for conversion to 700C oscillators to meet the new requirements as well as for replacement of the crystals when this is necessary.

CHAPTER 9

BROADCAST STUDIO AND CONTROL ROOM EQUIPMENT

Radio programs usually originate from a radio studio, although frequently theaters, halls, or other suitable places are employed. Radio studios range in size from very small rooms, just large enough to accommodate one or two persons, to very large auditoriums equipped with stages ample in size for elaborate productions and, in addition, providing seats for a studio audience of several hundred persons.

Associated with the studio are several rooms which are actually part of the complete studio unit. These include the control room, which will be described in detail later, and an observation room, which is usually provided for the use of the sponsor. The control room and observation room are separated from the studio by means of double-paned, soundproof glass windows, and the program is heard in these rooms by means of loud-speakers.

9–1. Studio Noise—A studio must have a very low acoustical noise level in order that extraneous noises will not be picked up by the studio microphones. Studios should be sound-isolated from the main structure of the building to prevent the transmission of external sounds as well as mechanical rumble and vibration into the studio. Equally important, sound isolation keeps sound within the studio, that is, prevents sound originating in the studio from being transmitted into adjacent studios and causing interference. Sound isolation is usually accomplished by insulating and separating the floor, walls, and ceiling of the studio from the main structure of the building by means of heavily padded hangers and supports. This results in the studio being literally suspended within the building structure. Further sound isolation is achieved by the liberal use of sound absorbing materials throughout the entire studio structure. Air conditioning is usually employed in radio studios, and, as this is a potential source of noise, the air ducts are lined with sound absorbing material. In addition, sound filters are placed in the ducts to prevent the transmission of vibration through these ducts into the studio.

Sound isolation is maintained at the entrance to the studio by means of a sound lock, which is usually an entrance foyer or hall with an outer door leading from the main corridor and an inner door leading into the studio. To enter the studio, it is necessary to pass through both doors. These doors are thick, heavy, well-gasketed, and soundproof. The entrance to the control room is often through a door located within the sound lock, a desirable feature since the sound lock is then also effective when passing from the control room into the studio.

A residual studio acoustical noise level of approximately 25 db (above the acoustical reference level of 10^{-16} watt per square centimeter) is satisfactory from an engineering point of view. Further reduction of the noise level, if possible, would be quite costly and would not be justifiable either technically or economically.

9–2. Studio Reverberation—One of the most important characteristics of a room used for radio broadcasting, whether it be a studio, an auditorium, or a theater, is its reverberation time. Reverberation time is the time required for sound energy to be completely absorbed or dissipated, and may be defined as *the time required for sound energy to decrease to a value one millionth (60 db) of its original value.*

Reverberation is due to a great many repeated reflections of sound waves from the surfaces of a room. These are not discrete reflections, as in the case of an echo, but rather hundreds of individual echos merged together. This reverberant sound continues to exist even after the original sound has ceased. The reverberation time is a function of the size of the room, the material used for the surfaces of the walls, floor, and ceiling, and the sound absorbing ability of all objects within the room. A room with hard, reflecting wall surfaces will have a comparatively long reverberation time. If the walls and ceilings of such a room are covered with a material of high sound absorptivity, the reverberation time will be reduced.

The reverberation characteristics of a studio must be near the correct value for the type of program being produced, if the program is to sound natural to the listener. For example, little if any reverberation is present in the open country, as there are few surfaces to cause reflections. If a radio program is being produced indoors in which the setting is intended to be outdoors, the illusion would be entirely destroyed if a large amount of reverberation were present, as the listener's mind would immediately associate the reverberation with an enclosed space. Similarly, a church organ or symphony orchestra, both of which are normally associated with large amounts of reverberation, would sound quite "thin" and unnatural if produced from a studio with a short reverberation time.

Radio studios are used for many different types of programs, such as dramatic sketches, speeches, string orchestras, popular music, and symphonic

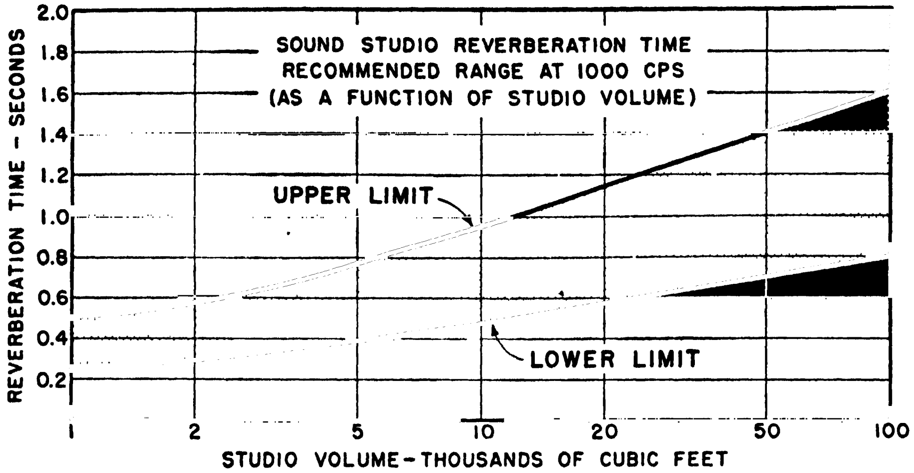

Fig. 9–1. Recommended reverberation time for broadcast studios. (Reproduced by permission from *Electrical Engineer's Handbook—Communications, Electronics,* Fourth Edition, by Pender and McIlwain, published by John Wiley and Sons, Inc.)

music. Each type of program requires a studio having reverberation characteristics best suited for it. In general, dramatic sketches and speeches require studios less reverberant than those required for musical productions. No one optimum value of reverberation can be chosen that will prove entirely satisfactory for all types of programs. Figure 9–1 shows a recommended value of reverberation time, at 1000 cycles, for studios of various sizes. The upper limit (most reverberant condition) is suitable for symphonic programs and other musical productions normally associated with large amounts of reverberation. The lower limit (least reverberant condition) is suitable for dramatic sketches or other program material where very small amounts of reverberation are required. Other programs will find their optimum value between the upper and lower limit.

The problem faced in designing a group of studios is how to provide reverberation characteristics suitable for all types of programs. In practice, several methods have been devised to accomplish this. One solution is to build some studios with rather high reverberation time and others with rather low reverberation time. A program is then assigned to a studio best suited, acoustically, to it. This method is entirely satisfactory technically, but is economically undesirable as efficient operation requires maximum use of each studio unit. Obviously, such an arrangement will require the construction of a larger number of studios than are actually required.

Another solution in common use is to construct all studios with reverberation characteristics best suited for musical productions. Then, when these studios are used for dramatic sketches or other programs requiring smaller amounts of reverberation, the characteristics of the studio are modified by the introduction of rugs, drapes, sound baffles, and screens, all of which tend to reduce the reverberation time. This method is satisfactory technically, but the constant changing of the studio acoustics by this time-consuming and laborious procedure is far from desirable.

In recent years, some studios have been designed and constructed in which the reverberation characteristics can be quickly and continuously adjusted. This is by far the most desirable solution, as the studio acoustics can be exactly adjusted to the optimum value for any type of production. Maximum use is therefore assured from each studio, and the possibility of a program being assigned to a studio acoustically unsuited to it is eliminated.

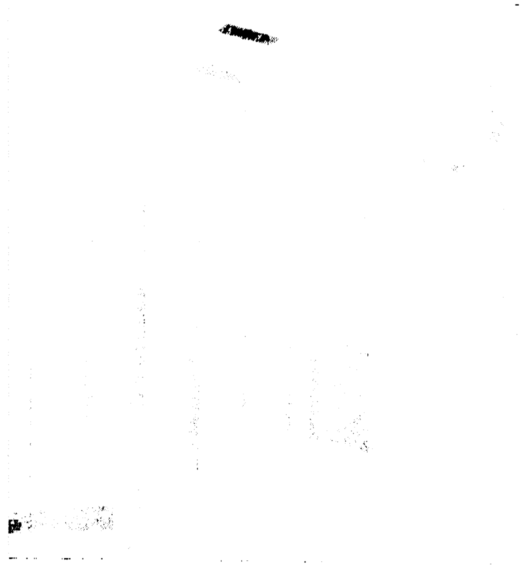

Fig. 9–2. A studio with adjustable acoustics. (Courtesy CBS.)

Figure 9–2 shows one type of studio employing variable reverberation characteristics. Extending from the floor to ceiling, over wide areas of the studio, are large hollow wooden panels, which have been named "acoustivanes." Each panel is pivoted at top and bottom and may therefore be rotated. All panels on each wall are ganged together in such a manner that they may be rotated simultaneously. The position of each wall of panels is controlled by means of suitable push buttons located in the control room.

When all the panels are completely closed, an unbroken, curved wooden wall is formed, and as this surface is of hard wood, the reverberation time of the studio is high. When all the panels are completely opened, a back wall treated with a sound absorbing material is exposed. This large area of sound absorbing wall surface thereby exposed results in the reverberation time of the studio becoming quite low. At various mid-positions of the panels, between the completely open and completely closed positions, various intermediate values of studio reverberation time are obtained.

The advantage of studios with adjustable reverberation characteristics is self-evident. Although the cost of the original installation may be higher than a more conventional studio, this increased cost will be offset by the fewer studio units required, inasmuch as maximum use will be obtained from each studio. In addition, fewer studio units result in lower overhead and maintenance costs.

9–3. Other Studio Acoustic Considerations— Although reverberation is perhaps the most important consideration in studio acoustics, there is another very important acoustic problem: interference between direct and reflected sound waves which results in the formation of standing sound waves. Standing waves are undesirable as they result in nonuniform distribution of sound throughout the studio. Standing waves usually occur in a room with plane wall surfaces and are formed when a direct and a reflected sound wave or two reflected sound waves, from the same source, meet. This results in the two waves combining and, depending on the phase relationship between the two waves, may result in anything from complete sound cancellation to a sound level corresponding to the sum of the two sound levels. At points where cancellation occurs, a "dead spot" results.

Standing waves, with the resulting non-uniform distribution of sound, are very undesirable and are to be avoided. In very early radio studios, standing waves were prevented by making the surfaces of the studios as acoustically dead as possible by means of a liberal use of sound absorbing materials. In this way, the sound waves were completely

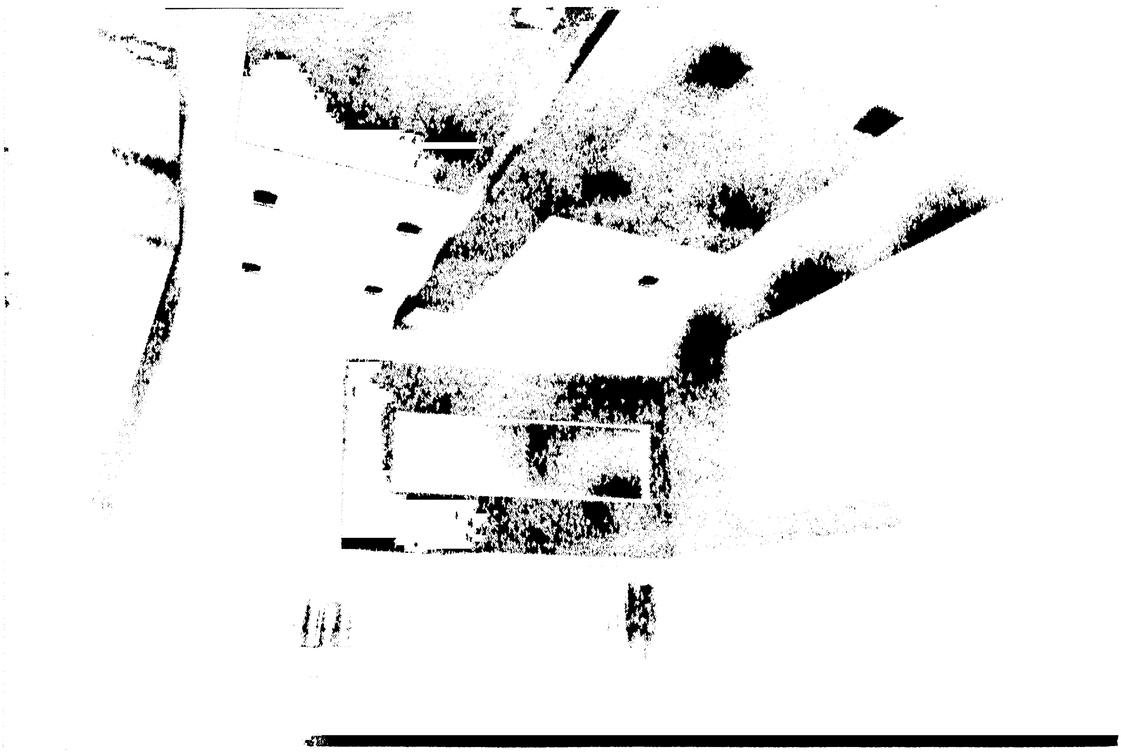

FIG. 9–3. A studio employing sloping-wall construction, wherein no two walls are parallel. (Courtesy CBS.)

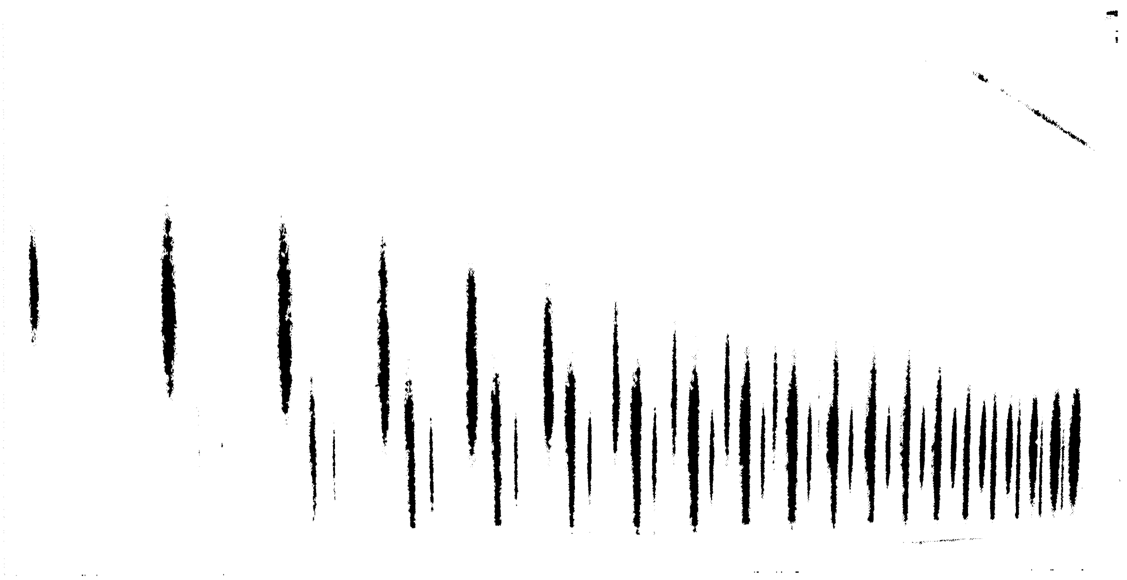

Fig 9–4 Polycylindrical wall surfaces of studio 6-A at Radio City, New York (Courtesy NBC)

Fig. 9–5. NBC's studio 6-D in New York which employs "diffusispheres" for sound diffusion. (Courtesy NBC)

absorbed and there were no reflections to cause standing waves. The fallacy with this approach was, of course, that if there is no reflected sound wave, there will be no reverberation, and reverberation is quite necessary in the production of modern radio programs.

Standing sound waves are eliminated, or greatly reduced, in modern radio studios by several means. One method, which has been frequently employed, is to have no two parallel wall surfaces in the studio. As standing waves are usually set up between two plane, parallel wall surfaces, this method is effective in preventing their formation. The floor and ceiling must also be taken into consideration and must not be parallel. An illustration of a studio using this sloping wall type of construction is shown in Figure 9–3.

Studio wall surfaces are often constructed in a manner that results in reflected sound energy being completely diffused, that is, scattered in all directions. This diffusion is effective in preventing the formation of standing waves and, in addition, has the added advantage that the reverberation characteristics of the room are improved. The latter advantage is due to the fact that complete diffusion of sound results in a smooth, logarithmic sound decay which is usually desirable in acoustic work.

Diffuse distribution of sound may be achieved in a number of ways. One method is the use of serrated walls and ceilings. Another method, even more effective, is the use of a multiplicity of convex, curved wood-panel surfaces on walls and ceiling. These panels, depending upon the shape of the surface, are known as either curvilinear or cylindrical sound diffusers. A studio equipped with cylindrical sound diffusers is shown in Figure 9–4. Still another method of sound diffusion employs many large hemispheres which are distributed over the studio surfaces. These hemispheres illustrated in Figure 9–5, have been given the rather appropriate name of "diffusispheres."

A studio to be acceptable for use in originating radio programs must be free from echoes. Echoes are not to be confused with reverberation. An echo is a distinct repetition of a sound caused by the reflection of the sound waves from a single surface or, in some cases, by more than one repetition due to reflections from several surfaces. Reverberation, on the other hand, is the result of a very great number of reflections which are incapable of being resolved into distinct echoes. In a studio in which the sound is well diffused by the wall surfaces, no difficulties should be experienced with echoes.

9–4. The Control Room—The studio control room contains the necessary mixing, amplifying, and monitoring facilities, described in detail later, by means of which the control room operator blends or "mixes" the various program material contributed

FIG. 9–6. Visibility into studio from control room is improved by having the window project slightly into the studio (Courtesy CBS.)

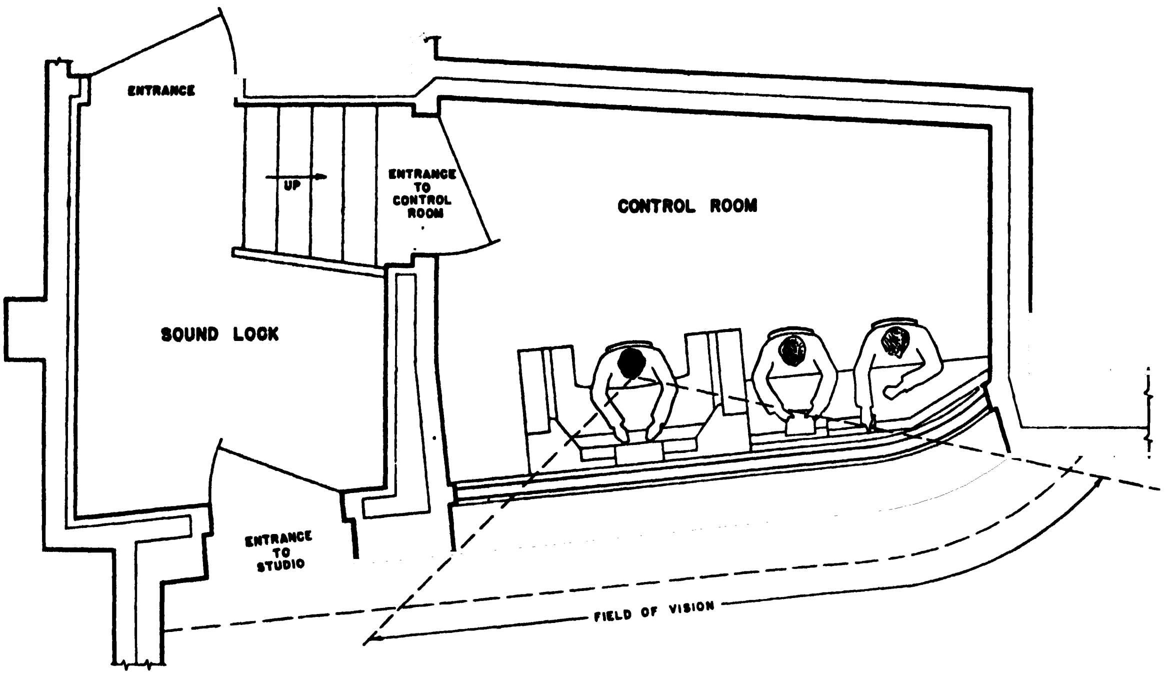

FIG. 9–7. Plan view of a studio control room. The operator is seated at the control desk, while the director and assistant director are seated at the desk to the right. (Courtesy CBS.)

by each microphone into a single program channel. In addition to the control room operator, this room is also occupied by the program director, one or more assistant directors, and occasionally by other persons associated with the program. Suitable space and facilities should be provided for all these persons.

It is very important that good visibility exist between the control room and studio. One method used to improve the visibility is raising the level of the control room floor. In medium and small size studios, a desirable height is that which results in seated occupants of the control room being at the same eye level as persons standing in the studio. In larger studios, used mainly for musical productions, an even higher level is employed which results in the seated control room occupants being at the same eye level as the orchestra conductor standing on a podium.

Visibility into the studio is further improved by the use of a very large control room window and still further improved if this window is allowed to project slightly into the studio, as shown in Figure 9–6. The glass is often set at an angle to prevent reflections from the overhead control room lighting. Two other important factors which are taken into consideration in improving good visibility are the height of the control panel and the distance the occupants of the control room sit from the window. Both should be small if good visibility is desired.

A plan view of a studio control room is shown in Figure 9–7. Entrance to the control room is from the sound lock and up a short flight of stairs, as the floor of the control room is raised above the studio floor level. Seating provisions are made for the control room operator and two other persons, for example, the director and assistant director.

A small control panel is usually provided on the director's desk. On this panel are mounted a talk-back key switch and an electric timing clock, similar in operation to a stopwatch, which is used during rehearsals for timing various portions of the program. A talk-back microphone is also provided for the use of the director.

9–5. Other Studio Facilities

1. *Talk-back Loud-speaker.* A loud-speaker is provided in the studio so the director in the control room can communicate with the performers in the studio during rehearsals. Such a loud-speaker is shown in Figure 9–8, in this case mounted on a panel together with the studio clock. It is usually desirable that this loud-speaker be located in the area above the control room window, as shown in the illustration, because of the desirable psychological effect of the voice through the loud-speaker coming from the actual direction of the person speaking. Some confusion, such as the performers turning their heads away from the director, may result if the loud-speaker is located in some other part of the studio.

2. *Microphone Receptacles.* Large wall plates, upon which the various microphone and other miscellaneous wall receptacles are centralized, are usually provided at several convenient locations in a radio studio. Such a wall plate can be seen directly under the control room window in Figure 9–8. On this wall plate are located four receptacles for studio microphones, receptacles for two general utility lines to the control room, a "headphone cue" receptacle into which headphones may be connected to hear the program as it is leaving the control room, and an extension of the private line telephone.

3. *Sub-studios.* In the production of radio programs, it is often desirable to employ, for certain special effects, a small room acoustically isolated from the studio proper. This is usually required in connection with portions of the program in which different reverberation effects from those in the studio proper are required, or in cases where special filters, known as sound-effect filters, are used to obtain unusual effects. This isolation is often accomplished by means of a small portable, soundproof booth, known as an isolation booth, which is equipped with a door, window, and provisions for the connection of a microphone and headphones. This need for such a sound isolation booth has been recognized as a constantly recurring problem, and some modern radio studios are being equipped with built-in isolation booths which are known as "sub-studios." These are small soundproof areas, with about 100 to 200 square feet of floor area, separated from the studio proper by means of a soundproof door. Good visibility is provided into this sub-studio from both the control room and the studio proper. Sub-studios are provided with appropriate microphone, headphone, and utility receptacles, and in some cases with a "talk-back" loud-speaker.

4 *Studio Storage Room.* Occasionally, a studio storage room is provided. A studio normally tends to accumulate an amazing array of miscellaneous equipment such as folding chairs, music stands, pianos, electric organs, isolation booths, platforms, and microphone stands. Needless to say, not

FIG. 9–8. A talkback loud-speaker, operated from the microphone in the control room, is mounted on the panel above the control room window together with the studio clock. The talk-back facilities are used only during rehearsals and interlock circuits are provided so the talk-back cannot be accidentally used while the studio is on the air. Note the large wall plate, upon which the microphone and utility receptacles are centralized, below the control-room window. (Courtesy CBS.)

all this equipment is required for every program and therefore is pushed to one side where it clutters the studio and reduces the usable working space. A large storage room repays its cost many times over by effectively increasing the size of the studio.

9–6. Units of Measurement—In this chapter, as well as others, reference is frequently made to the units "decibel," "dbm," and "vu." A complete knowledge and understanding of the meaning and correct usage of these terms is essential in the study of communication systems. These units are therefore discussed at this point, before dealing with the equipment employed in radio studios and control rooms.

9–6a. The Decibel—The decibel is a unit used to express the transmission gain or transmission loss of communication circuits or circuit components. The electrical powers encountered in communication circuits vary over a tremendous range; for example, the output of a microphone is but a few microwatts, yet this same power is amplified to several thousand watts in a radio transmitter. The ratio between two such powers represents a very large figure. It has been found convenient to express such power ratios in units of a system employing a logarithmic scale. This permits large power ratios to be expressed in small, easily handled numbers. The decibel (one-tenth of a bel) is the unit commonly used in practical work.

The number of decibels loss or gain in a circuit or circuit component may be found by the relation:

$$\text{db} = 10 \log_{10} \frac{P_2}{P_1}$$

where P_1 is the power at the input and P_2 is the power at the output.

The decibel can also be used to express voltage or current ratios when the two voltages or two currents operate in *equal impedances.* In this case the relation becomes:

$$\text{db} = 20 \log_{10} \frac{E_2}{E_1}$$

or

$$\text{db} = 20 \log_{10} \frac{I_2}{I_1}$$

If the impedances are not equal, the number of decibels loss or gain may be found by converting the voltages or currents to power and using the relationship already given for power ratios.

The following table shows the relationship between decibels and several power, voltage, and current ratios.

Power Ratio	Decibels	Voltage or Current Ratio	Decibels
0.00001	−50	0.00001	−100
0.0001	−40	0.0001	−80
0.001	−30	0.001	−60
0.01	−20	0.01	−40
0.1	−10	0.1	−20
1.0	0	1.0	0
10.0	10	10.0	20
100.0	20	100.0	40
1000.0	30	1000.0	60
10,000.0	40	10,000.0	80
100,000.0	50	100,000.0	100

In the past, the decibel was often used to express the audio power level existing at any point in an audio system. As the decibel expresses a ratio between two powers, this was accomplished by establishing a reference level and expressing the ratio of the power level in question to the reference level. Unfortunately, this practice became quite confusing as different reference levels were adopted by various

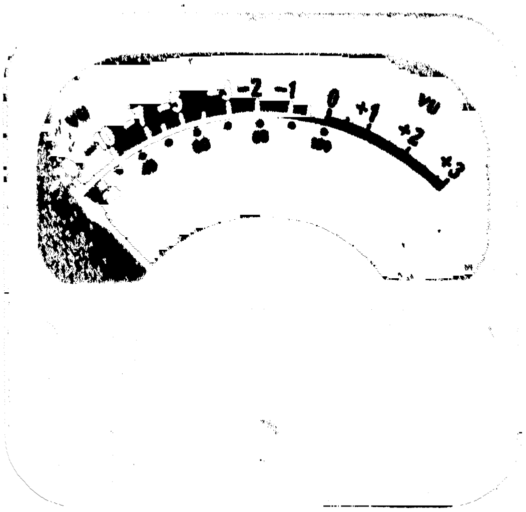

Fig 9–9a. The standard volume indicator—A scale.

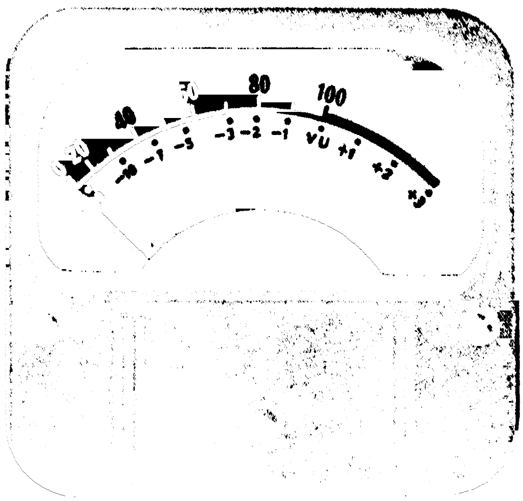

Fig. 9–9b. The standard volume indicator—B scale.

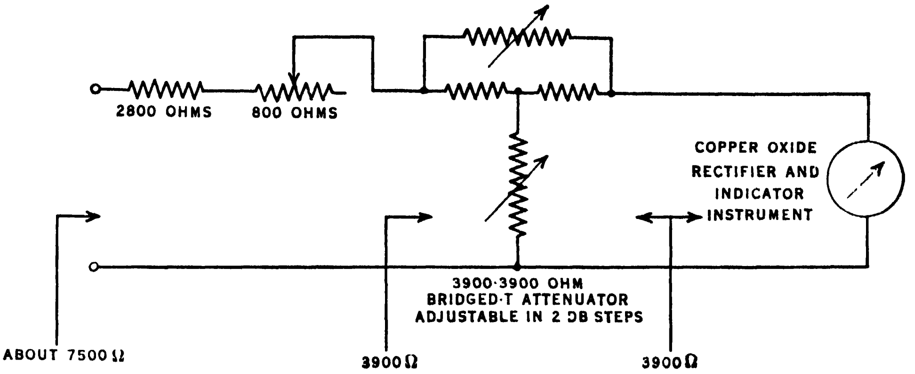
2800 OHMS
800 OHMS
COPPER OXIDE RECTIFIER AND INDICATOR INSTRUMENT
3900-3900 OHM BRIDGED-T ATTENUATOR ADJUSTABLE IN 2 DB STEPS
ABOUT 7500 Ω
3900 Ω
3900 Ω

Fig. 9–10. The circuit of the standard volume indicator. The attenuator permits the range of the instrument to be changed, in steps of 2 db, while the 800-ohm adjustable resistor allows a slight adjustment of the instrument sensitivity for calibration purposes. The lowest volume level capable of deflecting present-day instruments to the reference, or 100%, point is + 4 vu.

organizations. Reference levels of 1, 6, 10, 12½, and 50 milliwatts have all been in common use. This situation has now been completely cleared up with the acceptance by the industry in 1939 of a standard volume indicator, a standard reference level, and new units for expressing power and volume levels. Although the term *decibel* can be used to express power levels, provided the reference level is stated, this is no longer necessary, nor recommended, inasmuch as units are now available specifically for this purpose. The term *decibel*, therefore, should be used only as intended, that is, to express power ratios, such as the gain of an amplifier or the loss of an attenuation network.

9–6b. The Standard Volume Indicator—A volume indicator is an electrical indicating device, illustrated in Figure 9–9, used for measuring program and power levels. The instruments illustrated have been standardized and are now used by practically all radio stations in this country. A volume indicator is provided in the studio control room and, by means of this instrument, the control room operator is able to maintain the output of the studio at a predetermined level, this level usually being the value which results in program peaks modulating the radio transmitter 100 percent.

The standard volume indicator consists of a full-wave copper oxide rectifier and a d-c indicating instrument. An external attenuator and series resistor, connected as shown in Figure 9–10, are required to complete the assembly. The input impedance of the volume indicator is about 7500 ohms and is intended to be bridged across terminated 600-ohm lines. Rigid requirements have been established for the dynamic characteristics of the indicating instrument and copper oxide rectifier; therefore the standard volume indicator, when calibrated and used in the prescribed manner, will give an accurate indication of the volume level.

9–6c. The *Vu*—As can be seen in Figure 9–9, the standard volume indicator has two scales. One is a voltage scale, with arbitrary divisions ranging from 0 to 100. Readings on this scale are directly proportional to percentage of modulation of a radio transmitter. The other scale is calibrated in *vu* which is the measurement unit employed to express the "volume" of speech or program waves in communication systems. When the instrument is properly used, it gives an indication of volume level as so many *vu* above or below a reference volume, which is defined below, the number of *vu* being numerically equal to the number of decibels that the volume level is above or below the reference volume.

Inasmuch as the dynamic characteristics of the indicating instrument and the power law of the rectifier are involved, only levels read on the standard volume indicator, calibrated and used in the prescribed manner, may be expressed in *vu*.

9–6d. Reference Volume—The calibration of the standard volume indicator is stated in terms of its response to a steady, single-frequency signal. By definition, the reading of the standard volume indicator shall be 0 *vu* when it is connected to a 600-ohm resistance in which there is flowing one milliwatt of sine-wave power at 1000 cycles per second, or *n vu* when the calibrating power is *n* decibels above one milliwatt. Because of the complex waveform of program material, it does not follow that deflection of the volume indicator to 0 *vu* by a program peak indicates a program power level of one milliwatt. Actually, such a program peak may reach an instantaneous value many times one milliwatt, but have an average power much less than one milliwatt. The value of such program peaks cannot be easily described in terms of conventional units such as power, voltage, or current, but can be defined in terms of the deflection they cause on the standard volume indicator. Reference volume is therefore defined as *that level of program which causes a standard volume indicator, when calibrated and used in the accepted way, to read 0 vu.* In the special case of single-frequency sine waves, reference volume is one milliwatt.

9–6e. Dbm—Another unit, employed in performance measurements and performance ratings of audio facilities, is the dbm. The term *dbm* means "decibels referred to one milliwatt." A reading expressed in dbm indicates the power level of a *single-frequency test tone,* where the number of dbm is equal to the number of decibels the test tone is above or below a reference power of one milliwatt. The term *dbm* is used only with respect to steady state, sine-wave signals. While *vu* readings of program levels can be made only with the standard volume indicator, dbm readings can be made with any suitable a-c instrument, inasmuch as the dynamic characteristics of the meter are not involved.

The following table shows the relationship between dbm and sine-wave audio power.

Sine-Wave Audio Power (Watts)	Dbm
0.00000001	−50
0.0000001	−40
0.000001	−30
0.00001	−20
0.0001	−10
0.001	0
0.01	+10
0.1	+20
1.0	+30
10.0	+40
100.0	+50

9–6f. Correct Usage of Terms db, dbm, and *vu*—It is essential that the terms *db, dbm,* and *vu* be correctly used. Inasmuch as each term has a specific purpose, the use of the wrong term will invariably tend to confuse others.

The term *db* should be used only to express power ratios, such as the gain or loss in a given circuit or component; or the relative amplification of a device at one frequency as compared to another. The term *dbm* should be employed when referring to the actual power of a single frequency sine-wave signal; for example, the output level of an amplifier or complete system being tested or measured with test tone. The term *vu* expresses program level as read on the standard volume indicator.

As an example, an amplifier may have a gain of 60 db and a maximum output of + 30 dbm (1 watt). When used in a studio program circuit the output level of the amplifier may be maintained at + 14 *vu* as indicated by a standard volume indicator connected across its output terminals.

9–6g. Other Considerations—It has already been mentioned that the instantaneous power existing in a program circuit during a program peak may considerably exceed the value indicated by the volume indicator. Measurements have shown that on average program material the peak indicated on the volume indicator may be as much as 8 to 14 db below the actual peak value of the audio signal. The difference between the actual and indicated peaks varies for different types of program material, being high for male speech and piano music, and low for popular and symphony music.

An audio system must be capable of handling these peaks without overloading. To provide for this, it is common practice to design all amplifiers in a system to handle single-frequency, sine-wave power at least 10 db greater than the normal program level. Furthermore, all single-frequency test tone performance measurements of an audio system are made at a level 10 db greater than the normal operating level. This 10-db difference provides the necessary "headroom" to handle program peaks without excessive distortion.

9–7. Microphones—A microphone is an electro-acoustic device which converts sound energy into electrical energy. There are quite a few different types of microphones in current use. These can be classified into two general groups: (a) pressure-actuated devices and (b) velocity-actuated devices. The pressure-actuated microphone responds to pressure variations of the actuating sound waves, while the velocity microphone is actuated by the *difference* in pressure existing between the front and back of the microphone. Pressure-actuated microphones include the carbon, condenser, dynamic or moving coil, crystal, and pressure-actuated ribbon microphones. The velocity-actuated ribbon is an example of the velocity type.

Combination microphones containing both a pressure and velocity element are often employed to obtain directional characteristics such as the unidirectional or cardioid pattern. The combination units, which usually contain either a velocity-ribbon and dynamic unit, or velocity-ribbon and pressure-ribbon unit, are described in more detail later.

Desirable characteristics for microphones include: (a) adequate output level, (b) output waveform free from distortion, (c) output independent of frequency, and (d), in the case of the directional microphones, directional characteristics independent of frequency. In addition, all these characteristics should remain constant regardless of temperature or humidity conditions. The microphones most commonly employed for radio broadcasting at the present time are the velocity ribbon, the dynamic, the combination directional microphones and, to a lesser extent, the condenser.

The output level of modern, high-quality microphones is extremely low. The output of these units, when employed under average conditions in radio studios, requires amplifier insertion gains ranging from 60 to 70 db to raise the microphone output to 0 *vu.* In handling such low levels, extreme care must be taken to shield properly the microphone circuits in order to reduce the possibility of noise pick-up.

The electrical output impedance of microphones varies from a few ohms to many thousands of ohms. In broadcast work, microphone impedance has been standardized at 150 ohms,[1] which requires, in most cases, that a transformer be included inside the microphone housing. In the case of microphones with a very high electrical impedance, such as the condenser type, a complete amplifier stage is often included in the microphone housing.

A few of the problems encountered in the design of high-quality microphones are discussed below.

1. *Cavity Resonance.* When the diaphragm of a microphone is recessed or a cavity exists at the surface of the microphone, an acoustical resonator is formed. Because of the very small size of the cavity, its acoustical resonant frequency will usually be very high. This cavity will result in the pressure of the diaphragm being greatly increased near and at the resonant frequency with a resultant increase in output in this region.

2. *Diaphragm Resonance.* Some microphones are subject to another form of frequency distortion due to mechanical resonance of the diaphragm. Diaphragm resonance, when it occurs in the audible range, results in accentuation of the frequencies not only at the fundamental frequency of diaphragm resonance, but at harmonics of this frequency. Manufacturers often attempt to eliminate this effect by making the resonant period of the diaphragm above audibility.

3. *Frequency Response to Sound of Angular Incidence.* Variation of frequency response as a function of the angle of sound incidence is another cause of frequency distortion. When a microphone is employed to pick up a large orchestra or other large production, many of the sound waves do not impinge directly on the front of the microphone but reach it at various angles. If the frequency response in these various directions differs, the output will not be representative of the actual sound at the point of pick-up and frequency distortion results.

4. *Pressure-doubling.* A sound field is often disturbed by the presence of a microphone and, as a result, the pressure at the diaphragm of the microphone will not be the same as the pressure that would exist at the same point if the microphone were not present. This effect occurs only at high frequencies, where the wave length of the sound wave becomes comparable to the size of the microphone. The effect is one of sound diffraction and reflection, and the result is an increase in pressure at the diaphragm. Pressure-doubling is a function of the size and shape of the microphone and the angle of incidence of the sound wave.

9-8. The Carbon Microphone—The carbon microphone, although seldom used in radio broadcast work, finds a wide application in telephone communications. This microphone is reasonably rugged in construction, provides high sensitivity, and has an electrical impedance of about 200 ohms, which is quite suitable for direct transmission over wire lines.

The carbon microphone depends for its operation upon the principle that the resistance of a mass of carbon granules will change as the pressure applied to the carbon granules is varied. A small d-c current is passed through the microphone and, because of the resistance variations, the d-c current will vary in accordance with the sound pressure.

Figure 9-11 shows a cross-sectional view of a single-button, carbon microphone of the type used in telephone work. Anthracite coal is generally used for the carbon granules. They are enclosed in a small containing cup, constructed in a manner to prevent carbon leakage. When the microphone is subjected to sound vibrations, the pressure of the sound waves actuates the diaphragm. This results in the pressure being exerted on the mass of carbon granules, and the resistance of the carbon mass, therefore, varies in accordance with the variation of the sound pressure. The battery current flowing through the microphone will fluctuate, therefore, in accordance with the pressure variations of the sound wave.

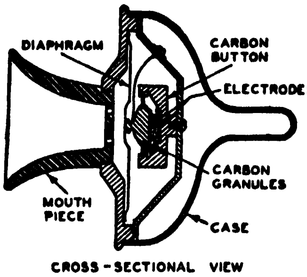

Fig. 9-11. The single button carbon microphone.

The diaphragm of the single-button microphone is usually designed so it will resonate in the frequency range between 1000 and 2000 cycles. This results in the microphone having maximum output in this range and accounts to a large extent for the high sensitivity of this type of microphone to voice frequencies.

When a carbon microphone with better frequency characteristics and lower distortion is required, a double-button carbon microphone is usually employed. An illustration of such a unit is shown in Figure 9-12. In this microphone, a stretched aluminum alloy diaphragm with a very high mechanical resonant frequency is employed, and a carbon cell is provided on each side of the diaphragm. To prevent oxidation, and insure good contact between the carbon granules and the diaphragm, the area of the diaphragm exposed to the granules is gold-plated.

When the diaphragm of the double-button carbon microphone is actuated by sound waves, the pressure on one carbon cell is increased, while the pressure on the other is decreased. This results in a push-pull action which tends to reduce distortion. Due to the fact that mechanical resonance of the diaphragm occurs at a very high frequency, usually between 5000 and 8000 cycles, the frequency characteristics of the double-button carbon microphones are fairly uniform, but the sensitivity is reduced, usually being about 15 to 20 db lower than in the single-button type.

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[1] Prior to the establishment of this standard in 1948 microphone impedances of 30, 50, and 250 ohms were in common use. A large percentage of the equipment still in service employs these impedances.

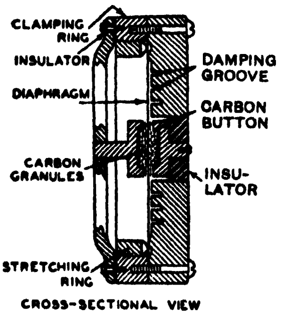


FIG. 9–12. The double button carbon microphone.

Both single- and double-button microphones have two disadvantages. The first is the fact that there is always present in the output a carbon hiss or noise, which is caused by the current flowing through the large number of contacts afforded by the carbon granules. The second disadvantage is the tendency of the carbon granules to adhere or "pack," which is usually brought about by the breaking of the circuit while current is flowing. This tends to reduce the sensitivity of the microphone and may result in the unit becoming inoperative. A simple filter arrangement, which reduces inductive kicks when the circuit is broken, is shown in Figure 9–13. This filter reduces the tendency of the carbon to pack.

9–9. The Condenser Microphone—In the condenser microphone, sound vibrations vary the electrical capacitance between two plates, one of which is the diaphragm, the other a fixed plate parallel with the diaphragm. The normal separation between the two plates is in the order of .001 inch and the dielectric between the plates is air. The diaphragm is usually constructed of aluminum alloy or stainless steel which is tightly stretched to make the mechanical resonant frequency as high as possible. A polarizing voltage of several hundred volts is required, which is applied to the condenser through a very high series resistance, usually many megohms, as shown in Figure 9–14.

Sound pressure causes the diaphragm to vibrate, resulting in the electrical capacitance of the unit

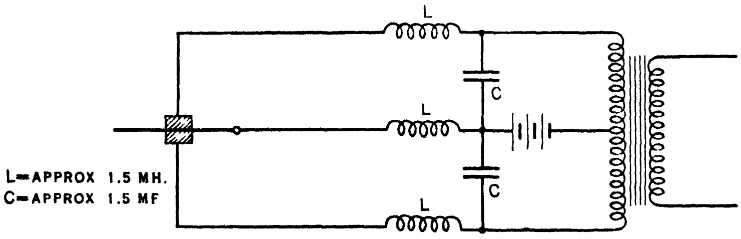


FIG. 9–13. The simple filter arrangement shown above is effective in reducing the tendency of the carbon granules to pack.

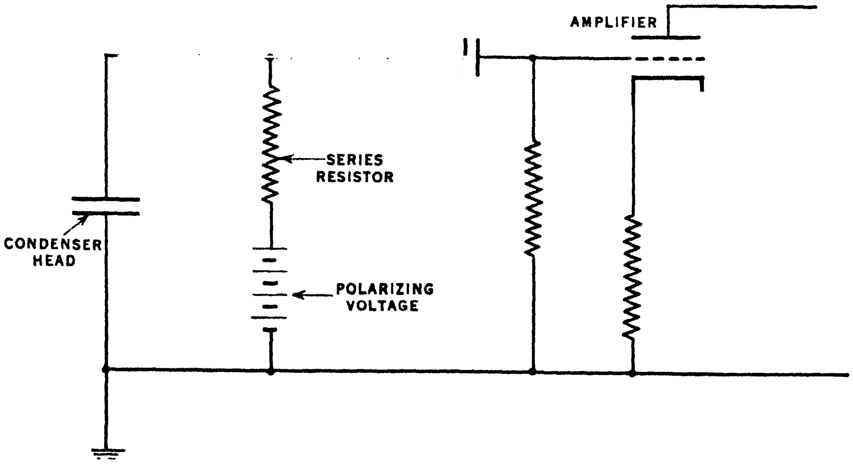


FIG. 9–14. Circuit arrangement of condenser microphone and associated amplifier stage.

varying in accordance with the variations of sound pressure. This, in turn, causes voltage variations, which constitute the output voltage, to develop across the series resistor.

Inasmuch as the output impedance of the condenser unit is extremely high, it is essential that the associated amplifier be immediately adjacent to the microphone. The amplifier is therefore usually mounted in the microphone housing. The amplifier voltages, as well as the polarizing voltage, are generally obtained from batteries.

The condenser microphone has low noise level, low distortion, and good frequency characteristics. It has two disadvantages: first, that it requires a high polarizing voltage, and second that the amplifier must be closely associated with the microphone. Because of the associated amplifier, the condenser microphone is usually rather large and, in addition, requires careful handling.

FIG. 9-16. The Western Electric 640AA microphone is no larger than a silver quarter.

FIG. 9-15. Western Electric 640AA condenser microphone with its associated RA-1095 amplifier.

9-10. W. E. 640AA Condenser Microphone—The Western Electric 640AA condenser microphone offers advantages which are in part due to its small size. As a laboratory instrument this microphone facilitates measurement of sound intensity over a wide range of temperature and humidity conditions. Production tests of other sound instruments such as receivers, loud-speakers and microphones may also be obtained through its use.

In the broadcasting field, when associated with its companion RA-1095 amplifier, the 640AA microphone provides a means for faithful program pick-up especially in auditoriums or in large studios which have proper acoustical characteristics for use of the remote single microphone pick-up technique. This application is particularly effective where orchestras or similar large groups are involved. The combination can readily be used with standard studio equipment since, under average conditions, a supplementary gain of approximately 40 db plus mixer loss is adequate to raise its output to a line-level of + 8 *vu*.

In all of these applications, the small size of the 640 type microphone diaphragm is a pronounced advantage from a fidelity standpoint. Physically it approaches the ideal of a point pick-up device, eliminating possible phase distortion, due to sound waves not striking simultaneously against different portions of the microphone diaphragm. Moreover, the smaller the pick-up device, the less the disturbance caused in the sound field by the mere presence of the pick-up element.

The 640AA condenser microphone is furnished in a bright metal cylindrical housing approximately one inch in diameter and one inch long.

9-10a. Frequency Response—The free-field response characteristics of the 640AA microphone mounted on the RA-1095 amplifier are shown in Figure 9-17. The range covered, it will be noted, is admirably suited to the highest quality program transmission requirements. With the line of sound approaching normal, or perpendicular to the plane of the diaphragm (0°), the response is approximately constant for sound in the frequency range between 50 and 1000 cycles. Above 1000 cycles, the response rises gradually to a maximum of about 8 db at 8000 cycles, then drops uniformly to a level which at 15,000 cycles is roughly equal to that at 1000 cycles.

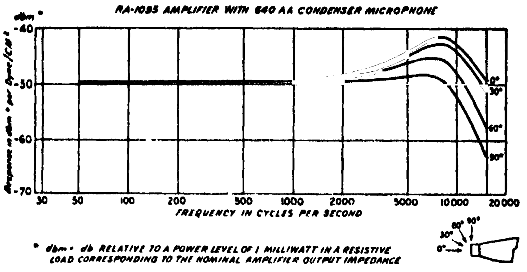


FIG. 9-17. Typical free-field response curve of the 640AA microphone mounted on the RA-1095 amplifier.

As illustrated in Figure 9-17, the response of the 640AA microphone varies somewhat in the higher frequencies depending on the direction from which the sound wave approaches the diaphragm. For sound 30° off normal incidence, the 8000-cycle maximum is reduced about 1 db. For sound 60° off normal, this level is reduced about 3½ db, and for sound 90° off normal about 7 db. The steepness of slope for frequencies around 10,000 cycles increases slightly with the degree of variation from normal incidence.

9-10b. Mounting—In mounting the 640AA microphone, it is important that its associated amplifier be arranged mechanically so as to preserve as nearly as possible the freedom from distortion of the sound field which is inherent in the small physical proportions of the microphone element.

The RA-1095 amplifier may be used for laboratory or production testing. Where especially constructed amplifiers are used in place of the RA-1095 amplifier, it is essential that connections between the transmitter and the first stage of vacuum tube amplification be short and of low capacitance as compared to the capacitance of the microphone; otherwise, the sensitivity of the instrument is reduced and its frequency characteristic altered. The lead to the grid of the head-amplifier tube should be well shielded electrically to prevent noise pick-up from interfering electric and magnetic fields.

For free-field pick-ups such as are common in broadcasting applications, the small, bullet-shaped Western Electric RA-1095 amplifier described on the following pages serves ideally both as a mounting for the 640AA microphone and as a means of providing the unit with first stage amplification and polarizing voltage. Where a microphone boom or other similar device is used to direct the microphone toward a given sound source, the amplifier should be shock-mounted by means of soft springs or rubber supports to isolate the elements from possible mechanical vibrations which are likely to produce noise.

9-10c. Technical Data

1. *Frequency characteristic:* Free-field response (see Figure 9-17).

2. *Output level:* Approximately 49.5 db below 1 volt (open circuit) per dyne/cm² with 200 volts d-c polarizing potential.

3. *Output impedance:* Essentially that due to its capacitance which is approximately 50 μμf to 60 μμf.

4. *Operates into:* Grid circuit of closely associated vacuum tube amplifier.

5. *Polarizing voltage:* 200 volts d-c from well-regulated quiet supply. *Caution:* Polarizing voltage exceeding 200 volts should not be applied as higher voltages may damage the instrument.

6. *Dimensions:* Cylindrical shape approximately 1 inch diameter and 1 inch long.

7. *Weight:* Approximately 1½ ounces.

8. *External connections:* The microphone should be connected to the grid of the vacuum tube by means of a short, well-shielded, low capacitance lead to center contact at rear of instrument. The cylindrical shell of the microphone should be connected to the grounded side of the grid circuit, thereby serving as a shield for the inner components.

9-10d. RA-1095 Amplifier—The Western Electric RA-1095 amplifier is a small, single stage amplifying unit developed especially for use with the 640 type condenser microphone. Shaped like a long-range military projectile, this amplifier is approximately 7¾ inches long by 2½ inches in diameter and weighs only 1¾ pounds. All components are housed in a removable spun metal casing which is normally finished in bright chromium but can be obtained in a nonreflecting, dark aluminum wrinkle gray.

A threaded recess at the pointed end of the housing permits screwing the 640AA microphone securely in place so that the two units present an unbroken surface offering the least possible disturbance to the surrounding sound field.

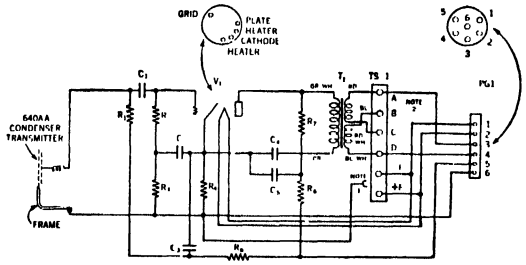
The screw mounting and case of the amplifier form the grounded side of the circuit. The high potential side of the circuit is completed to the 640 type microphone by means of a spring-mounted plunger in the center of the housing recess which connects with a center contact on the microphone.

The output level of this combination for a given sound field is about 28 db higher than that of a standard high-quality studio microphone, and the signal-to-noise ratio compares favorably. The frequency response characteristic of the amplifier is such as to assure optimum results from the use of the 640AA microphone. The free-field frequency response characteristics for the combination are shown in Figure 9–17.

9–10e. Power Supply—To operate the RA–1095 amplifier, 150 ma at 6.3 volts d-c are required for the heater or filament circuit, and approximately 3 ma at 200 volts d-c are required for the plate and microphone polarization supply. For maximum noise-free operation both sources of power should be extremely quiet.

Plate and polarizing supply voltages of less than 200 volts may be used but at a sacrifice in the microphone response level. The loss in the microphone sensitivity will be directly proportional to the decrease in polarizing potential from 200 volts. Voltages in excess of 200 volts should not be applied to the amplifier plate circuit when the 640AA transmitter is attached as higher voltages may damage the transmitter. If power is to be supplied from an unregulated rectifier, precautions should be taken against overvoltage.

Connections for plate and filament supply as well as for the program circuit leads are made through a standard 6-prong, recessed socket in the base of the amplifier, as shown in Figure 9–18. The Cannon plug, P6–11, will fit this socket. A thumbscrew is provided in the base of the amplifier so that pressure may be applied to the socket to hold these connections firm and allow suspension of the microphone and amplifier by means of the cord.



NOTE 1 Connect lead to −F or +F or leave open as a function of associated circuit grounds and observed noise level conditions

2 Strap B C for output to 150 250 ohm connecting circuits
Strap A B and C D for output to 25 50 ohm connecting circuits

Fig. 9–18. Schematic of the W.E. RA-1095 amplifier.

9–10f. Terminal Connections—A row of terminals arranged alphabetically is provided on the inside of the RA–1095 amplifier base to permit strapping for different impedance conditions. This row of terminals marked TS–1 is shown on the schematic drawing. The amplifier case is designed to slip easily off the narrow end of the chassis frame to allow ready access to these connections.

For connecting the amplifier to a 25–50 ohm circuit, terminal A should be strapped to terminal B and terminal C should be strapped to terminal D. For connections to a 150–250 ohm circuit, the previous connections should be removed and terminal B should be strapped to terminal C. The wire which carries the cathode return and ground connection to the filament supply circuit should be connected either to the − F or + F terminal, whichever may be found to give the lowest noise level conditions when the amplifier is connected to the succeeding circuits. The ground connection should not conflict with grounds on the external power supply.

9–10g. Mounting—It is recommended that a vibration isolation mounting be used with the RA–1095 in order to minimize microphonic disturbances.

9–10h. Maintenance—Other than occasional vacuum tube replacements, very little maintenance is required for the RA–1095 amplifier. The high impedance elements in the transmitter coupling mesh are impregnated with moisture-resistant compound to minimize noise difficulties due to moisture. The amplifier should be placed in a desiccator after it has been subjected to severe moisture exposure. Both the amplifier and the 640AA microphone should of course be protected from dust and corrosive fumes when not in use.

9–10i. Technical Data

1. *Frequency characteristics:* See Figure 9–18.
2. *Output level:* Approximately − 29.5 dbm with the 640AA microphone in a sound field of 10 dynes/cm^2 or − 49.5 dbm in a 1 dyne/cm^2 sound field.
3. *Signal-to-noise ratio:* Approximately 60 db at an output level of − 29.5 dbm (0–15,000 cycle band).
4. *Distortion:* One percent at − 3 dbm output level (− 29.5 dbm is approximate program output level under normal conditions).
5. *Operates from:* 640A or 640AA condenser microphone.
6. *Operates into:* 25–50 or 150–250 ohms.

9–11. The Dynamic Microphone—The dynamic microphone is a voltage generating, pressure-actuated device, in which sound vibrations cause a conductor to move in a magnetic field, thereby inducing a voltage in the conductor. The dynamic microphone is therefore, in effect, an a-c generator. Unlike the carbon and condenser types, it is completely self-contained, requiring no battery or polarizing voltages. The better types are quite rugged and stable.

The most common microphone of this type is the *moving coil* dynamic microphone. The moving coil microphone contains a diaphragm, usually made of aluminum alloy, phenolic, or paper, to which a coil of wire is rigidly attached. To keep the weight of the moving parts small, aluminum wire or ribbon is usually employed. The coil is located in the field of a strong magnet. When the diaphragm vibrates in response to sound waves, the coil is moved in the magnetic field and a small a-c voltage, corresponding in frequency and amplitude to the motion of the diaphragm, is induced in the coil. Acoustic networks are sometimes provided inside the microphone housing to improve the frequency response.

The electrical output impedance of the moving coil microphone is usually in the vicinity of 20 to 40 ohms. In many applications, this impedance is entirely satisfactory for transmission over cables of many hundred feet; however, when used for broadcast work, a small transformer is usually provided within the microphone housing to transfer the electrical impedance to the standard value of 150 ohms.

There are two other types of dynamic microphones in use which differ in construction from the moving coil type. One is the inductor microphone, the other the pressure-actuated ribbon microphone.

The *inductor* microphone contains a V shaped diaphragm with a single, straight conductor mounted along the bottom of the V. The operation is the same as in the case of the moving coil microphone; sound waves cause the diaphragm to vibrate and the single conductor is moved in a magnetic field. Because of the very short conductor employed, the electrical impedance is very low. A transformer is therefore installed in the microphone housing to step-up the electrical impedance to the desired value.

The *pressure-actuated ribbon* microphone employs a very light, corrugated metallic ribbon, usually made of aluminum alloy, which is suspended in a magnetic field, and which is free to vibrate in response to sound waves. This ribbon serves the dual purpose of both diaphragm and moving conductor. Only one side of the ribbon is exposed to the sound waves, the rear side of the ribbon being terminated in a highly damped acoustical chamber within the microphone housing. Sound waves cause the ribbon to move in the magnetic field, thereby inducing a small voltage in the ribbon. As in the case of the inductor microphone, the electrical output impedance is very low, and a step-up transformer is provided in the microphone housing.

FIG. 9–19. RCA type 88-A dynamic microphone.

Dynamic microphones are stable, reasonably rugged, and small in size. They have one disadvantage, that is, the frequency response usually varies with the angle of sound incidence.

9–12. RCA 88–A Dynamic Microphone—The type 88–A pressure microphone is a high-fidelity instrument of the pressure-actuated type which is especially designed for announcing and remote pick-up. Its smooth response and frequency range (60 to 10,000 cycles) make it suitable for reproducing both music and speech. It is effectively nondirectional when mounted in the vertical position and is semidirectional when mounted horizontally.

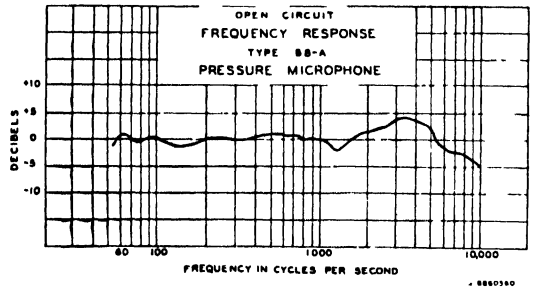


FIG. 9–20. Frequency response of 88-A microphone. (Courtesy RCA)

The moving element consists of a thin, moulded diaphragm to which is attached an annular coil assembly. Coupled to the diaphragm is an acoustic circuit so proportioned that the diaphragm velocity will remain essentially constant for a constant sound pressure over the range of frequencies from 60 to 10,000 cycles. The coil is located within the air gap of a magnetic structure and connected to a transformer which provides an output impedance of 50 or 250 ohms.

9–12a. Technical Data

1. *Effective output level:* -55 db (0 db $= .001$ watts) with an input sound pressure of 10 dynes/cm^2.
2. *Frequency response:* Essentially uniform from 60 to 10,000 cps.
3. *Output impedance:* 250 ohms, may be changed to 50 ohms.
4. *Physical dimensions:* Length 4⅝ inches, width 4⅛ inches, depth 4 inches (including mounting), weight 2 pounds.
5. *Directional characteristics:* Semidirectional when mounted horizontally, nondirectional when mounted vertically.

9–12b. Applications—The type 88–A microphone is particularly adapted for broadcast announcing and remote pickup. It is a small, lightweight microphone which may be used with a stand or carried in the hand for interview and mobile use. The relatively high output level is advantageous for remote work and provides a good signal-to-noise ratio. Since it is practically impervious to moisture and is not affected by temperature or pressure changes, it is especially adapted to outdoor use. Its construction makes the effect of objectionable air currents practically unnoticeable when it is used in the open air. This microphone is also excellent for many studio applications which require a nondirectional or semidirectional microphone.

9–12c. Directional Characteristics—When mounted in the vertical position, the type 88-A microphone is completely nondirectional but the higher frequencies are uniformly attenuated because of the physical size of the microphone. When mounted horizontally, the microphone is essentially nondirectional for frequencies below 2000 cycles. The higher frequencies are attenuated more as the angle with the perpendicular to the diaphragm becomes larger. Figure 9–21 shows the relative strength of sound pick-up from all angles when the microphone is in the horizontal position.

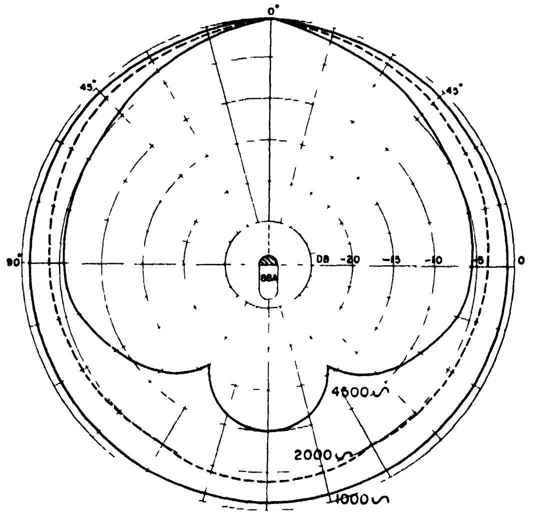


Fig. 9–21. Directional characteristics of a typical 88-A microphone. (Courtesy RCA.)

9–12d. Connections—The microphone is shipped connected for an output impedance of 250 ohms. The impedance can be changed to 50 ohms by removing the back of the case and making connections as shown by the dotted lines in Figure 9–22 after first removing the connector marked A in the schematic diagram. The case must be air-tight when reassembled as any leakage will result in a serious loss of low-frequency response.

9–12e. Recommended Load Impedance—It is recommended that the type 88-A microphone be worked into an unloaded input transformer.

9–12f. Phasing—When the outputs of two or more microphones are fed into a common mixing circuit, their respective outputs must be in phase. Otherwise the output of one will oppose the output of the other resulting in a reduction in output instead of a gain.

To check the phasing of two or more microphones, connect one microphone to the amplifier input and set the volume control to obtain the desired output level while talking into the microphone.

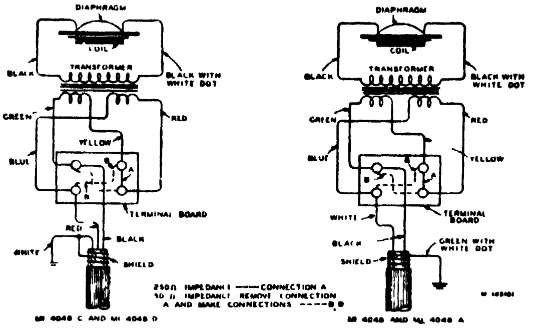


Fig. 9–22. Connections of RCA 88-A microphone. (Courtesy RCA.)

Then connect the second microphone in parallel with the first and, without changing the volume control setting, hold both microphones together and talk into them. If a decrease in volume results, reverse the connections of one microphone at the amplifier input terminals. Each additional microphone should be checked in a like manner and, if necessary, the cable connections reversed to correct the phasing to agree with the microphones already connected.

9–12g. Placement—When used in the studio, it should be kept in mind that correct placement of the microphone in relation to artists and instruments is of extreme importance. The requirements for particular installations vary widely and results will be determined best by experience. Exact placement must be determined by the following factors:

1. Wishes of the program producer.
2. Number and type instruments.
3. Size and construction of studio.
4. Peak volume swings as indicated by the volume level indicator.
5. Results as determined by actual monitoring.

In outdoor locations, it may be found that, because of the higher ambient noise level, the distance between the performer and the microphone must be less than when working indoors. It is important to maintain a relatively high input level of the desired signal in outdoor or remote locations in order to keep the signal-to-noise ratio as high as possible.

Care should be taken to protect the microphone from rough handling and exposure to rain and bad weather. While it is a rugged and practically weatherproof instrument, it is of the precision type and should be handled with care. Care in handling will be well repaid by the additional service received from the microphone.

9–13. The Velocity Microphone—The velocity, or ribbon, microphone employs a very light, loosely stretched, corrugated metallic ribbon, which is suspended in the air gap between the pole pieces of a strong permanent magnet. The mechanical resonant period of the ribbon is usually below audibility. Unlike the pressure-actuated ribbon microphone, already discussed, both sides of the ribbon are exposed to sound waves. The pole pieces of the magnet, in addition to supplying the concentrated magnetic field, also act as an acoustic baffle between the two sides of the ribbon. The ribbon moves when subjected to sound waves, because of the difference in instantaneous sound pressure on the front and back of the ribbon. The movement of the ribbon in the magnetic field causes a small voltage to be induced in the ribbon. As the electrical impedance of the ribbon is very low, a transformer is mounted within the microphone housing to step-up the impedance to the desired value.

The velocity microphone is bi-directional in response. Sound from a point directly in front or back of the microphone results in maximum difference of pressure between the two sides of the ribbon and, therefore, maximum output. On the other hand, sound from a point at either side of the microphone results in equal pressure at each side of the ribbon and, therefore, no output. Sound reaching the microphone from intermediate angles results in corresponding degrees of reduced sensitivity which can be plotted in the form of a figure eight response curve. This bi-directional response characteristic is very desirable in certain types of studio set-ups.

A well-built velocity microphone is a stable and reasonably rugged unit. It has quite smooth response-frequency characteristics and these characteristics remain constant for all angles of sound incidence. The velocity microphone must not be placed too close to the sound source. A distance of at least two feet between the source and microphone is essential, three to four feet being preferred. If this is not done, accentuation of the low frequencies with a resultant "booming" effect will be experienced.

9–14. RCA 44–BX Velocity Microphone—The type 44–BX microphone is a ribbon type microphone which operates on the pressure gradient principle and is especially designed to provide a microphone capable of reproducing sound with the fidelity required for modern radio broadcasting. The moving element is a very thin corrugated aluminum ribbon, suspended between the poles of a permanent magnet. The ends of the ribbon are connected to the primary of a transformer which raises the impedance of the ribbon to either 50 or 250 ohms. The ribbon is open to sound waves both front and back. Movement of the ribbon is due to the small instantaneous pressure differences existing between the two faces of the ribbon as a result of sound waves. Measurements have shown that a microphone of this type provides a sound responsive device with an exceptionally uniform frequency response throughout the audio range used in radio broadcasting.

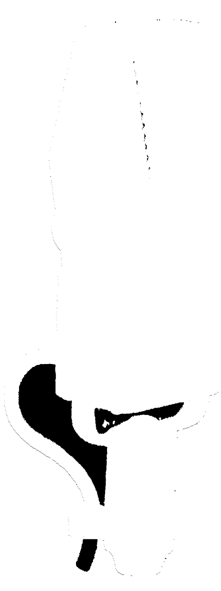


Fig. 9–23. RCA type 44-BX velocity microphone.

The sensitivity and frequency response of the type 44–BX microphone are practically unaffected by changes in temperature, humidity, and barometric pressure because of its type of construction. The ribbon and magnet assembly is protected against mechanical injury by a perforated housing. A cover plate on the bottom of the microphone provides access to the terminal board of the output transformer. The microphone is provided with a cushion mounting which is tapped to fit a ½-inch, straight pipe thread.

9–14a. Technical Data

1. *Output:* — 55[2] db effective level at 1000 cycles. 1.8×10^{-3} volts open circuit across 250 ohm tap. (With an input sound pressure of 10 dynes per square centimeter.)
2. *Output impedance:* 50 or 250 ohms.
3. *Directional characteristics:* Bi-directional, figure 8 pattern.
4. *Frequency response:* 30 to 15,000 cycles.
5. *Dimensions:* Length 12 inches, width 4¾ inches, depth, 3⅜ inches, weight 8½ pounds.

9–14b. Response Characteristic—Frequency response curves, taken with a plane progressive sound wave, are shown in figure 9–24. The response of the microphone can be altered to provide the characteristic most suitable for either music or voice by changing a jumper connection on the output terminal board. A small circular hole is provided in the cover plate of the transformer case through which may be seen the letter M (music) or V (voice), indicating whether the microphone is connected for music or voice.

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[2] 0 db = 0.001 watt.

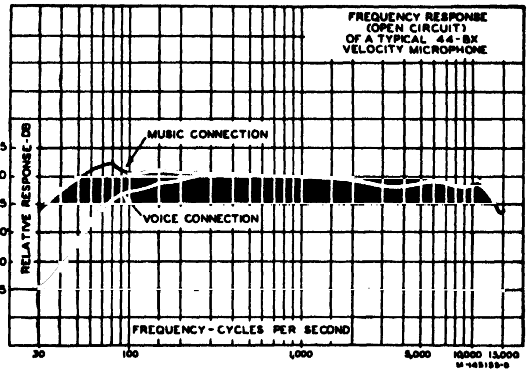

Fig. 9–24. Frequency response of 44-BX microphone. (Courtesy RCA.)

The response selector feature is incorporated for the sole purpose of supplying a microphone with the best possible characteristics for either voice or music pick-up. It is not intended that alterations in response will be made between numbers on a program. It is recommended that the microphone be connected for one of these types of service, and then the use restricted to that type of service.

9–14c. Directional Characteristics—One of the most important characteristics of the velocity microphone is its directional property. For equal distances from the microphone, the relative response to sound originating at various angles in a horizontal plane perpendicular to the ribbon is shown in Figure 9–25. Sound waves approaching the microphone from either direction along an axis perpendicular to the plane of the ribbon have the maximum effect. Sound waves from a direction in the same plane as the ribbon have little effect upon it.

A directional characteristic of this type results in a considerable reduction in the pick-up of background noise and reflected sounds because such sounds from side directions will have little effect. When used for public address or sound reinforcing purposes, the directional characteristic is of considerable value in reducing feed-back effects between the microphone and loud-speaker. The allowable operating distance of the velocity microphone is approximately 1.7 times that of a non-directional microphone of the same sensitivity.

9–14d. Connections—With the cover plate of the transformer housing removed, the output terminal board will be exposed. On one side of the terminal board there are four terminals (see Figure 9–26). The two outside ones are the output terminals, with one marked ± to indicate the phasing. The unit as shipped from the factory is connected for 250-ohm operation by having both the jumpers across the center terminals (marked 250). For 50-ohm operation, the two jumpers should be removed from across the center terminals and connected so that there is a jumper across each pair of terminals marked 50.

On the other side of the terminal board there are two terminals across which there should be a jumper marked V. This indicates the unit is connected for voice operation. For music operation this V jumper should be removed from one terminal and, with the other terminal as a pivot, turned 180° and then tightened. The letter M on the terminal board is now exposed, thus indicating the unit is connected for music operation.

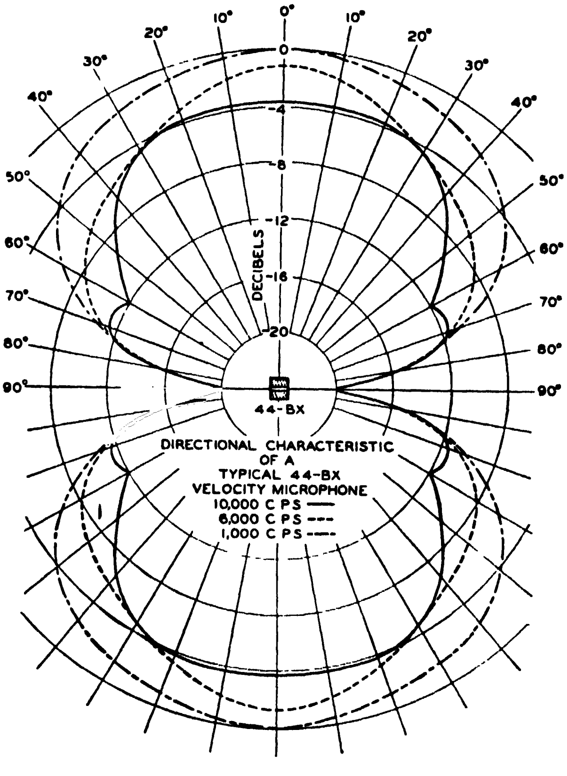

Fig. 9–25. Directional characteristics of 44-BX microphone.

9–14e. Phasing—When the outputs of two or more microphones are fed into a common mixing circuit, it is necessary that their respective outputs be in phase. If the microphones are not in phase, the output of one will oppose the output of the other. This not only results in a reduction in the output but also introduces distortion to a varying degree. *A velocity microphone may be reversed in phase by rotating the microphone through an arc of 180°.*

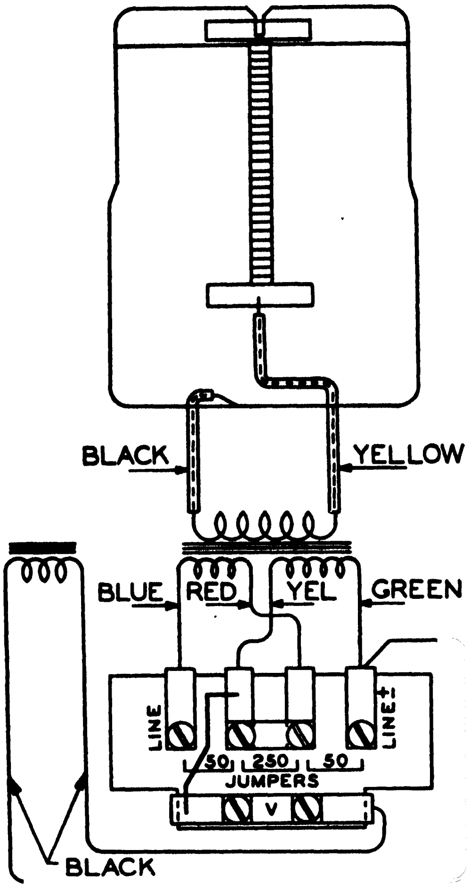

FIG. 9–26. Connection diagram of 44-BX microphone.

9–14f. Operation—The velocity microphone is especially well adapted to studio use where its directional characteristic and excellent response may be utilized to the best advantage. Since broadcasting studios are usually constructed so that there is an optimum of sound reflection within the room, the problem introduced because of echoes and reverberation is not a serious one. More attention may therefore be directed to the placement of the microphone so as to accentuate certain sounds and reduce others by means of the directional characteristics of the velocity microphone. Interesting effects can be obtained by different arrangements of instruments and performers about the microphone.

In order to secure the best results it is essential that the performers and instruments be grouped properly, and that all sources of sound be placed relative to the microphone so that each person or instrument will register with the proper relative intensity. The correct grouping and placement will be determined best by experience, since the requirements of individual set-ups vary widely. The following general rules may be helpful in developing the necessary technique for any particular situation.

1. Even when the voice connection is used, never place artists, speakers, or singers within less than one foot of the microphone, except for special effects. When the music connection is used, the best results are secured if the performer is three to four feet from the microphone. The low frequency response is increased if the source of sound is less than three feet from the microphone, and it is desirable to maintain this distance unless special effects are wanted. Voices tend to become boomy and unnaturally deep-throated if the performer is too close to the microphone. Beyond three feet, the response is as shown by the curves in Figure 9–24.

2. Place the microphone so that the source of the sounds that are to be reproduced will be either to the front or back of the microphone. Also, position the microphone so that the source of unwanted sounds is toward the sides of the microphone, where such sounds will be attenuated.

3. Place instruments having a low frequency range at greater angles with the perpendicular to the microphone ribbon, while instruments having higher frequency ranges may be placed in line with this perpendicular or removed from it only by small angles. The mid-frequency instruments are, of course, spaced in between those having the higher and lower ranges. Referring to the chart, Figure 9–25, which shows the directional characteristics of the microphone, will assist in placement of the various instruments and performers to the best advantage.

4. Protect the microphone from strong winds or loud explosive type sounds. Such sounds may stretch the microphone ribbon abnormally and necessitate replacement of the ribbon.

5. Place the microphone so that sound from the subject is received directly and not reflected sound from tables, walls, etc.

9–15. The Unidirectional Microphone—The unidirectional microphone consists of a nondirectional pressure-actuated microphone and a bidirectional velocity-actuated microphone, both contained in the same housing. The output of the two units is combined with the phasing so arranged that a cardioid or unidirectional pattern is obtained. In general, there are two types of unidirectional microphones; those employing a velocity-actuated ribbon and a pressure-actuated moving coil unit, and those employing a velocity-actuated and a pressure-actuated ribbon unit. In some units of the latter type, a single ribbon is employed, with the ribbon divided into two sections. One section is open at both sides, and is therefore velocity-actuated. The other section is closed at the rear by means of an acoustical labyrinth which removes the pressure from the rear and results in a pressure-actuated section.

Unidirectional characteristics result from this combination of two units in the following manner.

When a sound wave reaches the two elements from a point in front of the microphone, the voltages induced in each section are in phase and therefore add; but, when the sound reaches them from the rear, the induced voltages are 180° out of phase, and cancel.

In most unidirectional microphones, advantage is taken of the fact that two other characteristics, in addition to the cardioid or unidirectional response, are possible. One is a bi-directional pattern obtained by using the velocity-actuated unit alone; the other a nondirectional pattern by using the pressure-actuated unit alone. These microphones are therefore usually equipped with a switch permitting the selection of any one of the three characteristics.

The directional effects possible with these combination units are quite useful in many studio, as well as field, pick-ups. The unidirectional pattern is particularly desirable when it is necessary to discriminate against sounds coming from the rear of the microphone, such as would be the case in picking up an orchestra in a crowded night club. The construction of these units is usually quite rugged, and they are capable of withstanding reasonably rough handling, such as would be received in normal service. A disadvantage of the unidirectional microphone is the fact that the directional pattern changes as a function of frequency.

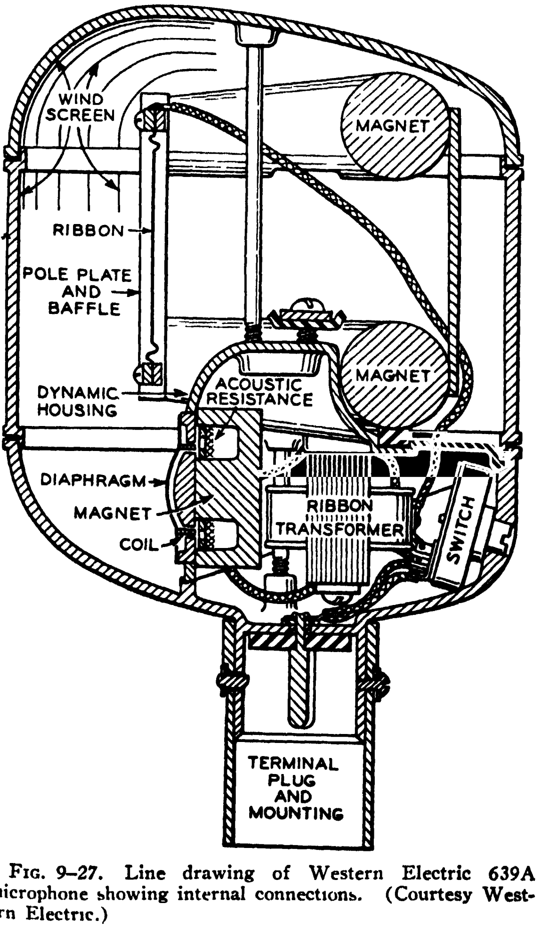

FIG. 9–27. Line drawing of Western Electric 639A microphone showing internal connections. (Courtesy Western Electric.)

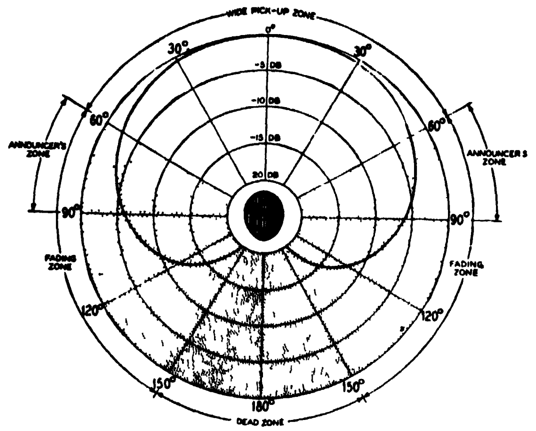

FIG. 9–28. Reference chart for interpreting the performance of the 639A cardioid directional microphone. (Courtesy Western Electric.)

9–16. Western Electric 639–A Cardioid Microphone—The Western Electric 639A cardioid microphone, illustrated in Figure 9–27, is a combination of a dynamic moving coil type pressure element and an improved ribbon type velocity element enclosed in an attractive housing which serves as a protective guard and as a wind screen.

When the outputs of these two elements are combined equally, the directional characteristic of the microphone is the heart-shaped cardioid curve C, shown in Figure 9–28. Use of the elements alone presents pattern D (dynamic) and R (ribbon). The cardioid directional performance of the 639A over the entire useful frequency range insures a practical, wide pick-up angle of at least 120° at the front of the microphone over which the quality is unchanged and the sensitivity remains practically the same. Sound engineers find this microphone invaluable for difficult studio, theater, auditorium, and night club jobs.

The 639A microphone is of such construction that it is sufficiently rugged to withstand the effect of normal handling, but it should not be subjected to abuse. Therefore, treat it with the same consideration as would be given to other types of precision devices. Keep the zipper cover on when the microphone is not in use. This will protect the finish and prevent accumulation of dust or iron filings. The housing grill is of weight-saving cast aluminum, and wide spacing between bars is necessary to permit sound to pass through. In transporting this microphone, as on remote jobs, always pack in a protecting box.

Because of a newly designed ribbon element which is of rugged construction, the 639A is much less susceptible to wind noise than usual ribbon microphones, and may be used satisfactorily under breezy conditions. However, ribbon microphones should not be subjected to extreme wind conditions and the 639A is not an exception.

The open circuit terminal voltage of the 639A microphone is approximately 64 db below one volt/10 dynes/cm^2. The frequency does not deviate from the average more than ± 4 db over the range from 40 to 10,000 cycles.

The 639A is designed for operation with input equipment which will work from impedances of 30 to 50 ohms. Use with amplifiers designed to work from higher impedances is possible under certain conditions, but care should be taken to consider the undesirable results of the mismatch.

In comparing the performance of the cardioid "C" position with either the dynamic "D" or ribbon "R" positions of the three-way switch, it should be remembered that the output level for "D" and "R" is 6 db lower than that of "C."

9–17. RCA 77–D Polydirectional Microphone—The RCA type 77–D polydirectional microphone is a high-fidelity microphone of the ribbon type. It is possible, as indicated by the name, to obtain a variety of directional patterns.

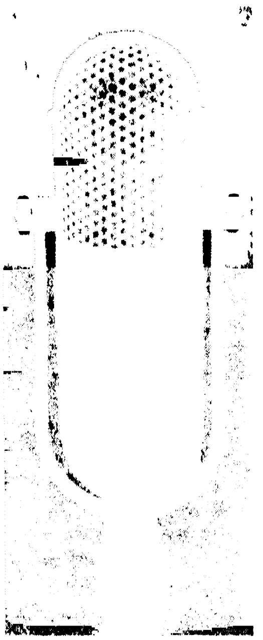

Fig. 9–29. RCA 77-D polydirectional microphone.

Instead of being open on both sides as in the conventional velocity microphone, the ribbon element in this microphone is coupled to an acoustic labyrinth which forms the body portion of the microphone. The tube connecting the back of the ribbon to the labyrinth is slotted directly behind the ribbon and fitted with an adjustable shutter to secure various areas of opening. When the opening is completely closed, the microphone operates as a non-directional pressure microphone; at the wide-open position, the microphone becomes bi-directional. With the proper size opening, the pattern becomes a cardioid by virtue of the phase shift which occurs. Openings smaller or larger than this critical size produce directional patterns with various sized rear lobes.

Different amounts of low-frequency attenuation are obtained by a reactor shunting the output.

9–17a. Technical Data

1. *Output impedance:* 50, 250 and 600 ohms.
2. *Load impedance:* Open circuit.
3. *Effective output level at 1000 cycles*[3]
   Bidirectional (B): – 54.3 dbm
   Unidirectional (U): – 57.3 dbm
   Nondirectional (N): – 60.3 dbm
   L–1, L–2, L–3: between – 54.3 and – 57.3 dbm.
4. *Dimensions and weight*
   Length: 11½ inches Width: 3¾ inches
   Depth: 2½ inches Weight: 4½ pounds.

9–17b. Application—The 77–D microphone is intended for use in broadcast studios, high-fidelity sound systems and similar applications. It is intended primarily for indoor use and if used outdoors may require some additional protection against wind.

The choice of directional patterns makes possible a considerable degree of control of the ratio of direct sound to reverberant sound as well as the possible reduction of unwanted sound such as audience noise in a studio. The wide angle of pick-up provided by the cardioid pattern is useful in covering large groups with a single microphone. For close-talking applications the nondirectional characteristic is of considerable value since the low-frequency response is not accentuated as in the case of a velocity microphone. Numerous other applications of the various directional patterns as well as the different response curves will no doubt suggest themselves to the user.

9–17c. Connections—As shipped, the microphone is connected to show an output impedance of 250 ohms. To connect the microphone for an output impedance of 50 or 600 ohms, first lower the bottom cover by removing the four machine screws around the rim of the cover. Pull the cover down until the transformer terminal board connections are accessible. For the proper cable connections, refer to Figure 9–30.

9–17d. Directional Characteristics—The adjustable shutter over the slot in the tube leading to the acoustic labyrinth may be rotated by means of a screwdriver adjustment extending through the rear screen flush with a designation plate.

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[3] Sound pressure = 10 dynes/cm^2.

The plate is marked U, N and B, as symbols for the unidirectional, nondirectional and bi-directional patterns. Three additional markings L–1, L–2 and L–3 are used as reference points for other directional patterns which may be obtained. Refer to Figure 9–31 for the patterns associated with each of the six symbols. Stops are provided on the continuously-variable pattern selector at the six marked positions, although the shutter may be set at any intermediate position.

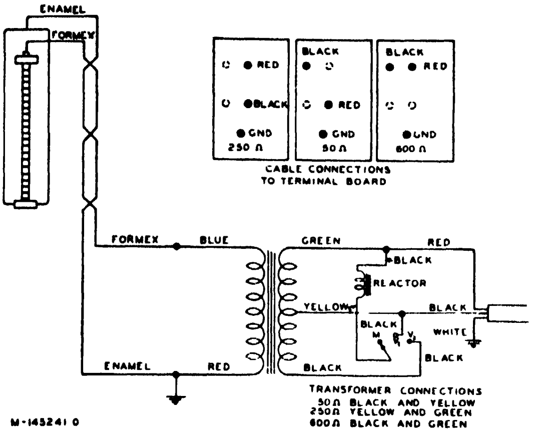


FIG. 9–30. Schematic and connection diagram for RCA 77D microphone. (Courtesy RCA)

9–17e. Frequency Response—At the bottom of the lower shell is a screwdriver-operated selector marked M (music), V_1 and V_2 (voice). The voice positions connect a reactor across the entire secondary or part of the secondary of the output transformer, depending on the switch position (see diagram, Figure 9–30). Refer to Figure 9–32 for the frequency response characteristics of each setting. As can be seen from the curves, the reactor attenuates the low frequency response. This is especially desirable when the microphone is less than three feet from the source of sound as the low frequency response would otherwise be exaggerated.

9–17f. Frequency Response Settings—For sound sources greater than three feet from the microphone, the frequency response selector can be used in the M position for any of the directional response patterns. If the nondirectional characteristic is used, no low frequency attenuation should be required even for very small distances. If the bi-directional or unidirectional patterns are used, low frequency attenuation will be required when the sound source is less than three feet from the microphone, unless special effects are desired. It is suggested that the V_1 position be used for distances down to one foot and the V_2 position for still shorter distances. Refer to Figure 9–32 for the frequency response curves of the M, V_1, and V_2 settings.

9–18. Crystal Microphones—A crystal microphone makes use of the piezo-electric properties of certain crystalline substances, notably Rochelle salts, for the generation of a voltage as a result of stress exerted on the crystal element by the pressure of sound energy. Two types of crystal microphones are in use: the "diaphragm" type, where the sound pressure causes a diaphragm to move, which, in turn, drives the crystal element; and the "sound cell" type, where the sound pressure acts directly on the crystal element. The diaphragm type is more sensitive, but its frequency response is not as uniform as the sound cell type.

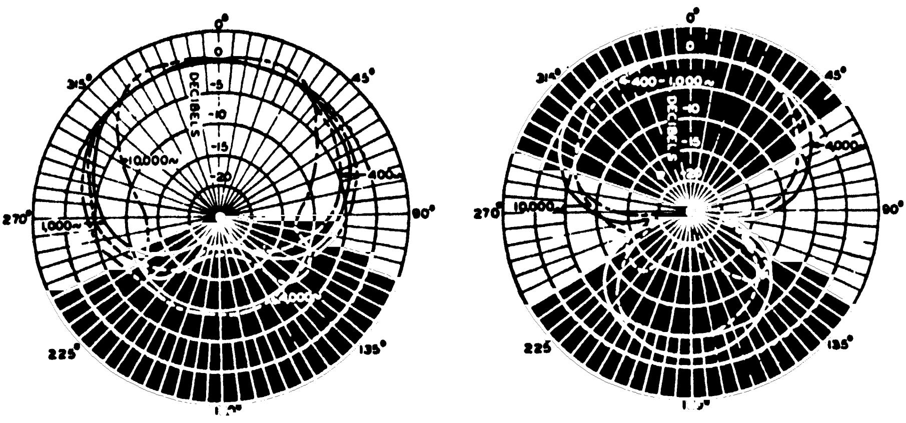
The crystal element consists of two or more Rochelle salt crystal plates cemented together. The two most commonly used crystal plates are known as "expander" and "shear" plates, depending upon the angle of cut from the crystal bar. The faces of each crystal plate are ground smooth whereupon graphite or metal foil electrodes with suitable leads are applied. The plates are then properly oriented and cemented together. Such an assembly of two or more plates is known as a "bimorph." When two or more "expander" plates are employed, the resulting unit is known as a "bender" bimorph. Two or more "shear" plates form a "twister" bimorph. These terms are descriptive of the actual bimorph deformation which results should an electrical voltage be applied to the element. The assembled bimorph element is usually coated with a moisture proofing preparation to protect it from moisture and humidity.

The sensitivity of the crystal microphone varies to some extent with temperature, having a maximum output at temperatures of 70° to 90° F. Satisfactory operation is obtained at temperatures ranging from $-40°$ to $+130°$ F, but, if exposed to temperatures in excess of $+130°$ F, the crystal will lose its piezo-electric properties permanently.

Inasmuch as the crystal element is essentially a pure capacitance, the output of the microphone can be carried to an amplifier located a reasonable distance away by means of a suitable low-capacitance cable. This will result in a loss of output level, but the frequency characteristics will not be impaired.

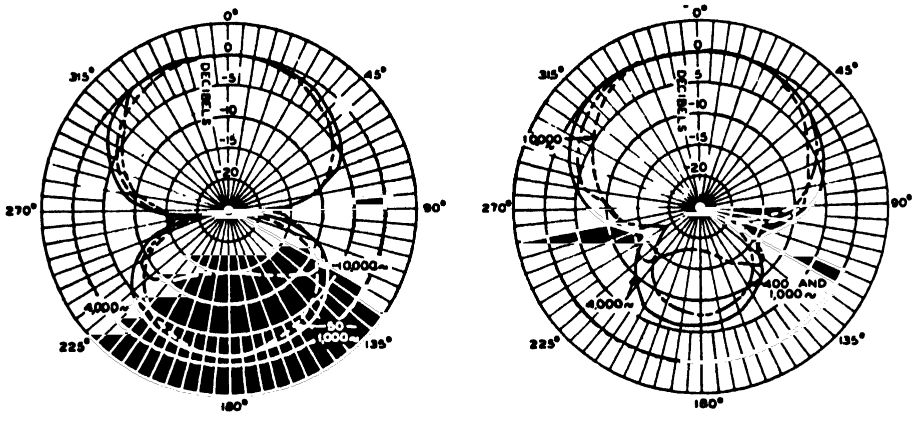
The output impedance of the crystal microphone is quite high, and these units are therefore usually operated directly into the grid circuit of a vacuum tube. For this reason, crystal units are seldom employed in broadcast audio facilities, where a microphone impedance of 150 ohms has been standardized.

9–19. Control Room Audio Facilities—The fundamental requirements of the audio facilities in the studio control room are to provide the necessary amplification, mixing, and monitoring facilities to prepare properly the program material from microphones or other program sources for transmission to special program lines which carry the program to the radio transmitter. In small radio stations



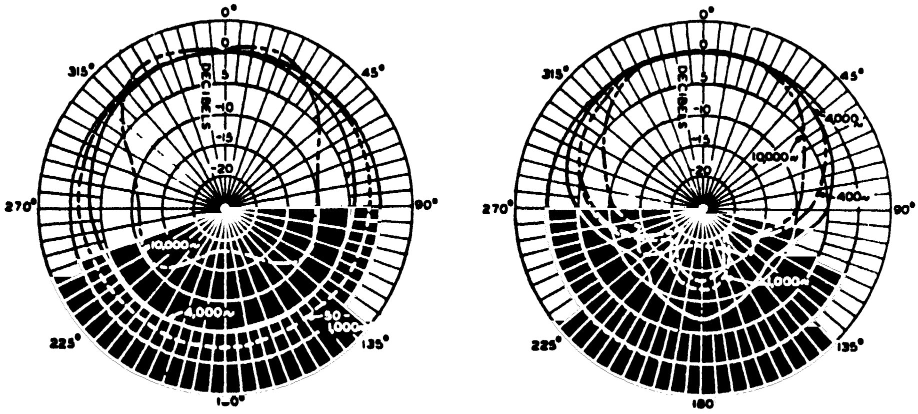
UNI-DIRECTIONAL POSITION

L-1 POSITION



BI-DIRECTIONAL POSITION

L-2 POSITION



NON-DIRECTIONAL POSITION

L-3 POSITION

FIG. 9–31. Directional patterns of RCA 77-D microphone. (Courtesy RCA.)

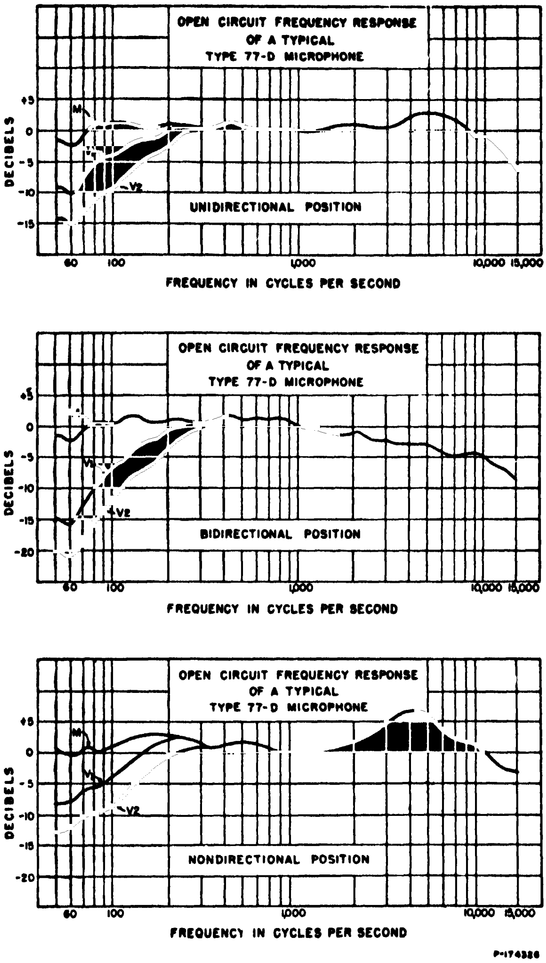


FIG. 9–32. Frequency response curves of RCA 77-D microphone. (Courtesy RCA.)

with only one control room, the line to the transmitter is fed directly from the control room; in larger stations with many studios, the program is transmitted to a "master control" room from which point the program is switched to wire lines feeding the transmitter, or transmitters.

The studio and control room, in either case, must provide the following basic facilities:

1. Microphones or other sources of program material.
2. Amplifiers to raise the extremely low output of microphones to a level suitable for transmission.
3. Mixing controls, by means of which the program material from several different program sources is blended together, as well as a "master volume control," by means of which the over-all level of the mixed program can be adjusted without affecting the balance.
4. Aural and visual monitoring facilities.

In addition to the above basic facilities, other supplementary features are usually provided, such as "talk-back" and "cue" facilities, as well as emergency audio and power facilities to insure continuity of service in any emergency.

The importance of continuity of service in broadcast operations cannot be overemphasized. There are two very important underlying reasons for this. First, broadcasting in the United States is supported by means of commercial programs in which a sponsor pays for the use of the broadcast time and facilities of the station for advertising purposes. Should a technical error or equipment failure cause a loss of a part or all of such a sponsored program, it is customary for the station to make a refund to the sponsor. The second reason for absolute continuity of service lies in the reaction of the listener to an interruption in program service. The average listener, who will remain tuned to a station even if he is not particularly interested in the program being transmitted, will become impatient very quickly when subjected to long pauses or "dead air" and will tune his receiver to another station. A technical failure, even of short duration, will therefore result in a station losing a large percentage of its audience.

Figure 9–33 shows, in block diagram form, a typical six-position studio audio mixing installation. Two of the six inputs are associated with studio microphones, two with transcription turntables, and two with incoming program lines. Such an arrangement is commonly encountered in the average radio studio. Each component employed in this illustration, with the exception of microphones which have already been covered, is described in the following paragraphs.

9–20. Preliminary Amplifiers—At the output terminals of a microphone there exists a signal voltage and, in addition, a noise voltage. The noise voltage is thermal in nature and is caused by the random movement of electrons in the atomic structure of the microphone circuit. Such noise voltages contain components of every possible frequency and will be found to exist across the terminals of any resistance. This is known as "thermal agitation," and when amplified and reproduced, these noise voltages result in the hissing noise often erroneously referred to as tube hiss. This thermal agitation voltage is exceedingly small, its value in microphone circuits in the audio frequency range being in the vicinity of — 130 *vu*. However, the output signal level from the microphone is also quite low, ranging from — 60 to — 70 *vu* in present day dynamic and velocity microphones. Thus it can be seen that a signal-to-noise ratio of 60 to 70 db exists at the microphone terminals. Inasmuch as good engineering practice requires signal-to-noise ratios of this magnitude from the over-all audio system, the remainder of the system can contribute very little additional noise.

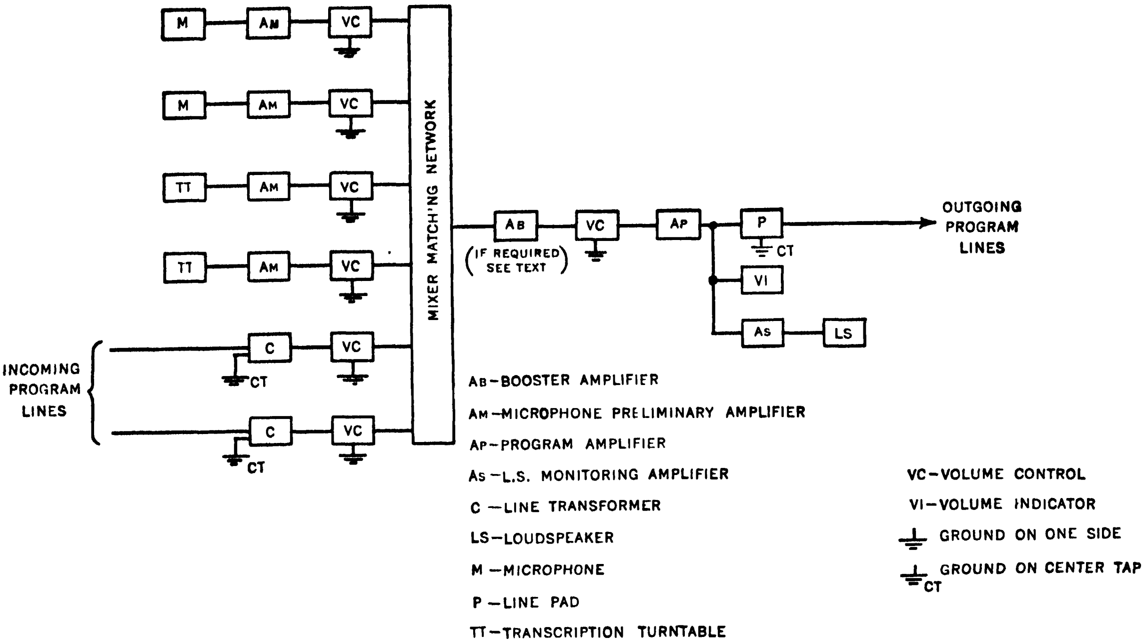


FIG. 9–33. Typical studio audio facilities, providing six mixer positions.

A volume control, or "mixer," is normally associated with each microphone. The resistance elements forming this volume control also generate thermal agitation noise voltage of the same magnitude as that appearing at the microphone terminals. If the microphone were to be connected directly to this volume control, the already very low output of the microphone would be still further attenuated *but the noise would remain the same* (at the thermal noise level), and the signal-to-noise ratio would be greatly degraded. Therefore, before the volume control can be introduced into the circuit, it is necessary to raise the level of the signal voltage until it is well above the thermal noise. Accordingly, small one- or two-stage amplifiers having a gain of 30 to 40 db are commonly employed between each microphone and its associated mixer control. These amplifiers are known as preliminary amplifiers.

An audio mixing system, in which these preliminary amplifiers are employed, is known as "high level mixing." A mixing system in which preliminary amplifiers are not used is known as "low level mixing." Low level mixing cannot be recommended for high-fidelity audio facilities where a maximum signal-to-noise ratio is required. In a system such as illustrated in Figure 9–33, the signal-to-noise ratio would be degraded by approximately 25 to 35 db if low level mixing were employed.

Preliminary amplifiers must be carefully designed to have the lowest possible noise level, as any noise contributed by them will be amplified by all the following amplifier stages. The input transformer, which is operating at an exceedingly low level, must be provided with the very finest electromagnetic and electrostatic shielding. A low-noise tube of special design, such as the type 1603 or 1620, is usually employed in these amplifiers. This tube is shock mounted to reduce tube microphonics as much as possible. Finally, great care must be exercised in circuit design to reduce the hum level to the lowest possible point.

Inasmuch as no control of volume takes place between the microphone and preliminary amplifier, the amplifier must be capable of handling rather large output levels without overloading. It must be realized that the rated output of microphones is for normal sound levels, but when a speaker shouts directly into a microphone or a loud musical instrument, such as a trumpet, is play directly into a microphone, the output level of the microphone and of the preliminary amplifier will exceed the normal value, in some cases by as much as 30 db. The preliminary amplifier must be capable of handling these large output levels without overloading. Inasmuch as good amplifier design requires that an amplifier be capable of a sine-wave output 10 db greater than the normal maximum output, in order to provide for program peaks, a preliminary amplifier with a gain of 40 db should be capable of handling output levels as high as +20 dbm (0.1 watt) without excessive distortion.

In radio work it is a basic rule that the impedances of any interconnected circuits must be matched, but the case of the microphone and preliminary amplifier is an exception to this rule. Low-impedance microphones, such as the dynamic and velocity types, are basically voltage-generating devices and their output impedance is *not* matched to the input impedance of the preliminary amplifier. The amplifier input impedance is actually many times the microphone impedance and thereby practically the entire open-circuit voltage of the microphone is impressed across the amplifier input terminals. This is a case of maximum voltage transfer, not power transfer, and by operating the microphone into an open circuit in this manner, two times the voltage is impressed across the amplifier input as would be the case if the impedances were matched. This is equivalent to a gain of 6 db and results in a better signal-to-noise ratio than if impedance matching were employed. As the microphone is almost always coupled to the grid of the first amplifier tube by means of a transformer, the amplifier input impedance is made high by omitting the terminating resistor from the secondary side of this transformer.

The output impedance of preliminary amplifiers used in broadcast work has been standardized at 600 and 150 ohms. The output of the preliminary amplifier is matched to the mixer volume control in the conventional manner.

9–21. Langevin Type 116–A Amplifier—The type 116–A amplifier is a small, plug-in, two-stage, medium-gain, low-noise preamplifier or booster amplifier for use in broadcast audio facilities, recording facilities, or sound systems.

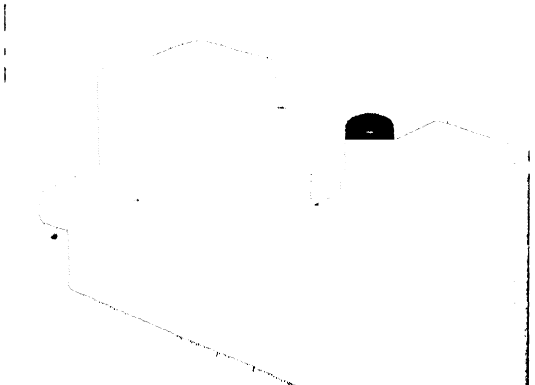


FIG. 9–34. Langevin 116A preliminary amplifier.

9–21a. Technical Data

1. *Gain:* 40 db with provision for adjusting to 34 db.

2. *Input source impedance:* 30/150/250/600 ohms. Center taps are available when strapped for 150 or 600 ohms.

3. *Output load impedance:* 150 or 600 ohms. Center tap is available when strapped for 600 ohms.

4. *Output power:* + 18 dbm (.063 watts) with less than 0.5 percent rms total harmonic distortion over the range 50 to 15,000 cps, and less than 1 percent total harmonic distortion over the range 30 to 15,000 cps.

5. *Output noise:* Unweighted, equivalent to an input signal of − 120 to − 124 dbm, depending upon input tube, over the band 50 to 15,000 cps.

6. *Frequency characteristics:* ± 1 db over the range 30 to 15,000 cps.

7. *External power requirements:* Filament: 6.3 volts a.c. at 0.6 amp. Plate: 275 volts d.c., 8 ma.

8. *Tube complement:* Two 1620's.

9. *Dimensions:* Length 10 inches, width 2 inches, height 5 inches, weight 4 pounds.

9–21b. Connections

Plug Pin Numbers	Circuit
1 2	Input*
3	Chassis ground
4–6	Output†
5	Tube current meter (If metering push buttons used)
7	Tube current meter (positive) VT-1
8	Tube current meter (positive) VT-2
9	Blank
10	Blank
11–12	Filament 6.3 volts a.c 0.6 amp
13	B − and meter (negative)
14....	B + 275 volts d.c.

* On unbalanced input circuits, the grounded side should be connected to pin 1

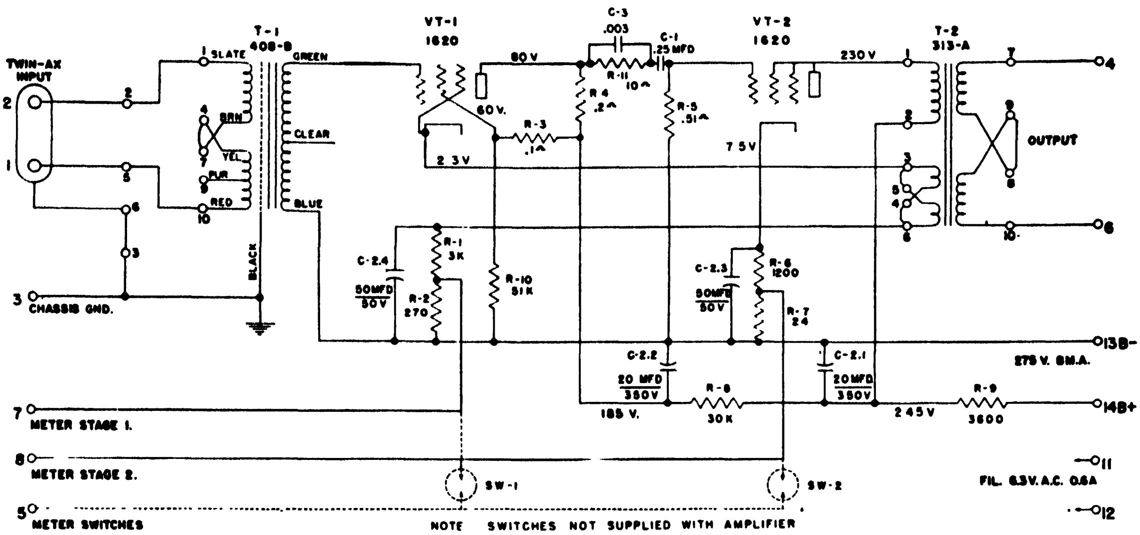
† On unbalanced output circuits, the grounded side should be connected to pin 6.

9–21c. Metering Circuits—Metering circuits are designed to measure the cathode current of the individual tubes expressed as a percentage of a normal tube, using a meter having a 200 microampere movement. A series resistor should be added so that the total resistance of the meter and resistor is 1000 ohms. The meter scale should be calibrated so that nominal cathode current (100 percent) will read at 75 percent of full scale.

The amplifier is supplied with the metering connections of the individual tubes brought out to pins on the plug for use with an external meter switch. However, provision has been made for push button meter switches in the handle end of the chassis if it is desired to meter the tubes at the amplifier.

9–21d. Grounding—Connect the main ground to pin 3 on the plug receptacle. Ground the negative side of the plate supply in the following manner: When one amplifier is being used, strap pin 13 to pin 3. When several amplifiers are used in a system, and obtain plate power from a common source, apply the ground at only one point in the system.

The center tap of the filament supply should be grounded. In some cases, however, it may be neces-

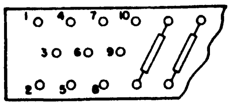


INPUT IMPEDANCE	STRAPPING ON RESISTOR STRIP
600ω	1-2, 4-7, 5-10.
250ω	1-2, 4-7, 5-9
150ω	1-2-4, 5-7-10.
30ω	2-9, 5-10.

OUTPUT IMPEDANCE	STRAPPING ON OUTPUT TRANSFORMER
600ω	8-9.
150ω	7-9, 8-10.

GAIN	STRAPPING ON OUTPUT TRANSFORMER
40DB	3-5, 4-6.
34DB	4-5.

NOTE THE VOLTAGES SHOWN ARE TYPICAL AVERAGE VALUES OBTAINED USING A 11 MEGOHM VOLTMETER WITH NO SIGNAL INPUT AND CONNECTED TO POWER SUPPLIES INDICATED.
VOLTAGES ARE IN REFERENCE TO B-



RESISTOR STRIP NUMBERING

FIG. 9–35. Schematic diagram of Langevin 116A preliminary amplifier.

sary to apply positive bias to the filament center tap with respect to ground, in order to reduce hum caused by filament to cathode leakage. In this event, a resistor can be connected across the plate voltage supply so that a portion of the plate voltage, 6 to 12 volts, can be tapped off and fed to the filament center tap.

9–21e. Impedance—The 116–A amplifier, as shipped, is connected to work from a source impedance of 30 ohms and into a load impedance of 600 ohms. If other impedances are desired, the amplifier may be restrapped in accordance with the table on Figure 9–35. Strapping for the input is accomplished on the terminal strip; for the output on the output transformer.

Center taps are available on the input of the 116A amplifier when the unit is strapped for 150 or 600 ohms and on the output when strapped for 600 ohms. The input center tap can be grounded on the terminal strip. In order to ground the output center tap, run an additional wire from a ground point to the output transformer terminals.

9–21f. Gain—This amplifier is supplied with a gain of 40 db. The gain may be reduced to 34 db by restrapping the feedback windings on the output transformer, according to the table on Figure 9–35.

9–21g. Tube Substitutions—In an emergency, if a 1620 vacuum tube is not available, a 6J7 tube can be substituted. This substitution may result in a decrease in output power and an increase in output noise level.

9–22. Mixer Circuits—Mixing is the process of combining the outputs of a group of volume controls into a single program channel. It is through the use of mixer circuits that the program material from several different microphones are combined, or blended, in the proper proportions, to obtain the desired overall effect. By the skillful manipulation of a group of mixers, it is possible to create a pleasing balance of all elements of a program.

Various transition effects are commonly achieved by using the mixer controls to "fade-out" one scene and "fade-in" another. Mixers are also used to "fade-down" a musical transmission to permit announcements to be made over the music. Because of these functions, the mixer controls are often referred to as "faders."

9–22a. Mixer Controls—Mixer controls are usually variable resistance attenuation networks, and there are two different types in general use, the "bridged-T," and the unbalanced-to-ground "ladder" type.[4] Mixer controls in common use provide attenuation at a uniform rate over the greater portion of their range until an attenuation of approximately 40 db is reached, whereupon the attenuation increases rapidly in the last few degrees of rotation until a maximum attenuation of approximately 120 db is reached. The standard impedance of these units for broadcast work is 600 and 150 ohms. These attenuators must perform their function smoothly without noticeable jumps in level as the arm of the attenuator passes from contact to contact. In addition, they must not contribute any noise into the system.

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[4] Balanced-to-ground versions of these controls are also occasionally employed. In general, these consist of two of the above-mentioned units mounted on a common shaft.

Fig. 9–36. A variable bridged-T resistance attenuation network commonly employed as a mixer control in audio facilities. (Courtesy The Daven Co.)

A bridge-T type of mixer control is illustrated in Figure 9-36, and its circuit arrangement is shown in Figure 9–37. The bridged-T network is electrically equivalent to a regular T network but requires only two adjustable resistance elements instead of three. The input and output resistance of the bridged-T network remains constant within quite narrow limits over its entire attenuation range and this type of network has no insertion loss when set to the point of minimum attenuation. Because of these advantages, the bridged-T type mixer is employed in audio systems where the very finest performance is required.

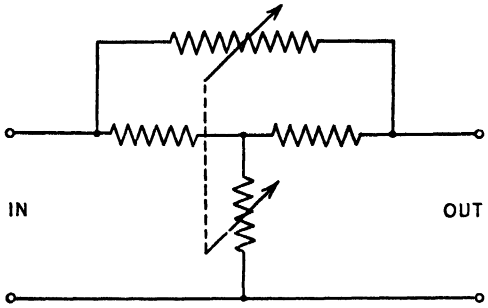


Fig. 9–37. Circuit arrangement of bridged-T mixer control.

A ladder type of mixer control is illustrated in Figure 9-39, and the circuit arrangement is shown in Figure 9–40. The ladder network has the disadvantage that it introduces an insertion loss of 6 db. In addition, the input and output impedances, although within reasonable limits, depart more from the rated value than in the case of the bridged-T network, particularly at the two extremes of rotation. Ladder controls of special design are available in which the insertion loss has been reduced considerably by employing a two-to-one impedance

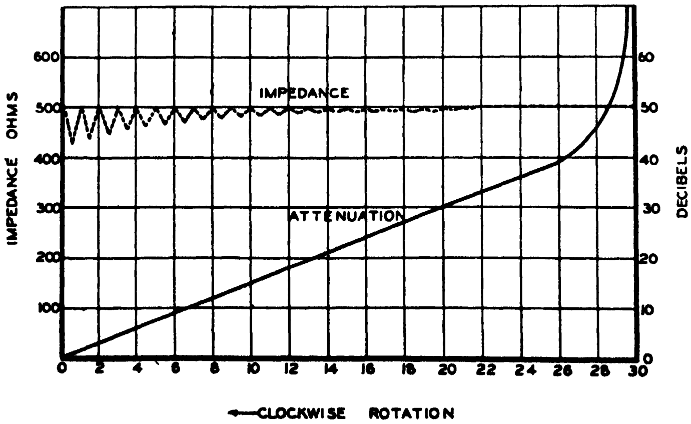


Fig. 9–38. Impedance versus attenuator setting for the bridged-T network. The impedance curve shown applies to both the input and output circuits of the attenuator. These data are for an attenuator having a nominal impedance of 500 ohms, with 30 steps of 1.5 db attenuation per step. The rate of attenuation increases rapidly on the last three steps. (Courtesy The Daven Co.)

Fig. 9–39. The ladder type of variable resistance attenuation network also employed as mixer control in audio facilities. (Courtesy The Daven Co.)

ratio, that is, the input impedance is one half the output impedance, or vice-versa.

The ladder control is simpler in construction than the bridged-T type inasmuch as only a single row of contact points are required. This simpler construction results in a lower cost and for this reason ladder controls are usually employed where cost is an important consideration.

9–22b. Master Volume Control—A master volume control is provided to permit adjustment of the over-all output level of the studio without affecting the balance achieved by means of the mixer controls. By means of this control, it is possible to set the mixers for the proper program balance and then control the over-all level with a single control. The master volume control is also useful for fading in and fading out at the beginning and conclusion of a program.

It is common practice to employ the same type of unit for the master volume control as is used for the mixer controls, that is, a bridged-T or ladder attenuator with uniform attenuation characteristics over the greater portion of its range and rapid attenuation on the last few steps.

9–22c. Mixer Matching Network—A mixer matching network is a resistance network designed to combine the outputs of the mixer volume controls into a single channel. To accomplish this properly, the mixer matching network must provide correct impedance relationships between all circuit components. The requirements for the mixer matching network may be stated as follows:

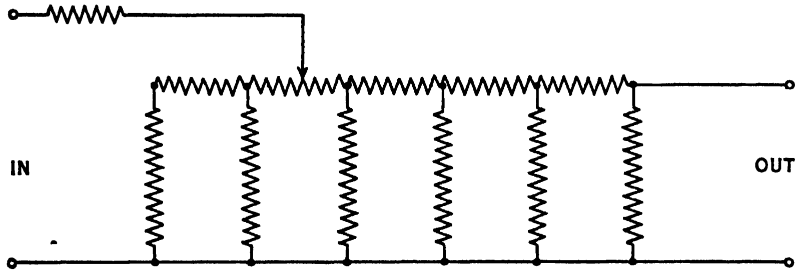


Fig. 9–40. Circuit arrangement of unbalanced-to-ground ladder mixer control.

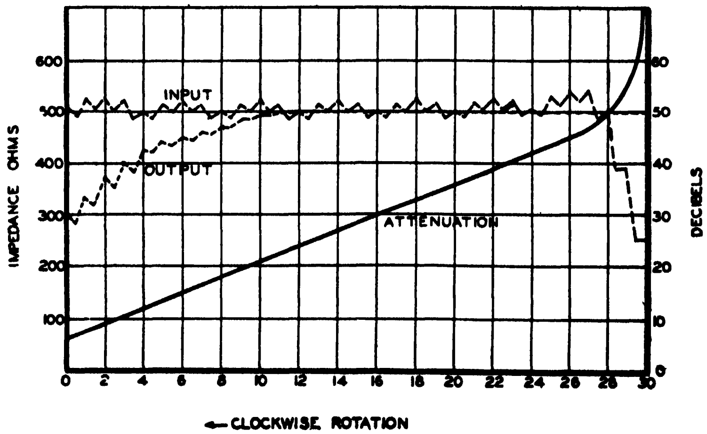


Fig. 9–41. Impedance versus attenuator setting for the ladder type network. These data are for a unit with a nominal impedance rating of 500 ohms, and having 30 steps of 1.5 db attenuation per step. The rate of attenuation increases rapidly on the last three steps. (Courtesy The Daven Co.)

1. The mixer matching network must properly combine the outputs of all mixer controls into a single channel.
2. It must also provide a correct load impedance for each mixer control.
3. In addition, it must provide the correct source impedance for the following circuit element, which may be a master volume control, or in some cases, a booster amplifier.

Figure 9–42 shows the circuit arrangement of a mixer matching network having like input and output impedances. The values of the series resistors are given for circuits with from two to eight mixer controls, as well as the network loss in each case. Values for mixer circuits with more than eight positions can be found by use of the design equations which are given.

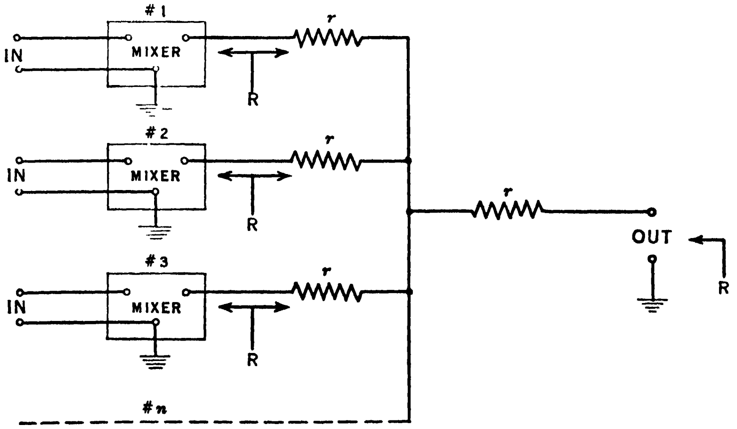
If the attenuation introduced by the matching network of Figure 9–42 is too great, Figure 9–43 shows another arrangement with lower insertion loss. This network is known as a "minimum loss" matching network and entails the use of a special matching transformer to restore the output impedance to the same value as the input impedance or to any desired value. This transformer must be of the best possible design if present-day frequency response standards are to be met and, in addition, must be equipped with the finest electromagnetic shielding to prevent hum pick-up.

It is common present-day practice to employ a microphone preliminary amplifier as a booster, and, as these amplifiers have a very high input impedance, a special matching problem arises. A mixer matching network for use under these circumstances is shown in Figure 9–44.

9–23. Booster Amplifier—If the maximum signal-to-noise ratio is to be obtained from an audio system it is important that the signal level at any point in the circuit never be allowed to fall below the signal level existing at the output terminals of the microphone. The attenuation introduced by the mixer control and matching network is often sufficient to cause this to occur at the output of the master volume control unless amplification is provided between the mixer matching network and the master volume control.

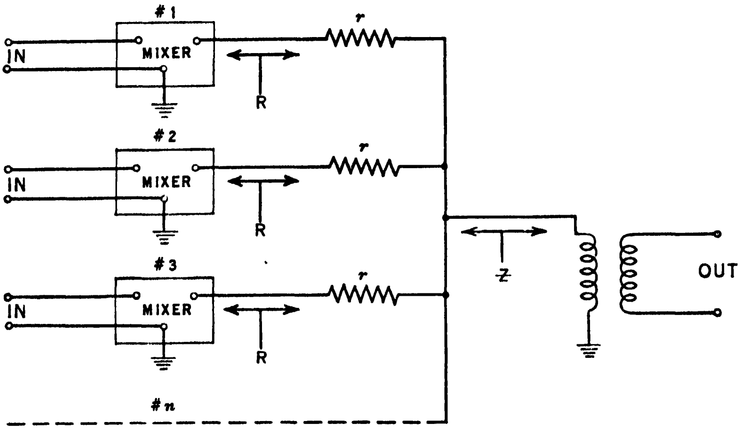
An amplifier employed for this purpose is known as a "booster" amplifier and usually consists of one or two stages of amplification with a gain of 30 to 40 db. In broadcast work, booster amplifiers are designed to operate from a source impedance of 150 and 600 ohms into a load impedance of 600 and 150 ohms. It is common practice to use a microphone preliminary amplifier as a booster, but inasmuch as these amplifiers have a very high input impedance (although designed to operate from a source impedance of 600 and 150 ohms) special consideration must be given to the design of the mixer matching network. This has already been discussed in the preceding section.

9–24. Program Amplifier—Because of the attenuation introduced by the normal operating set-



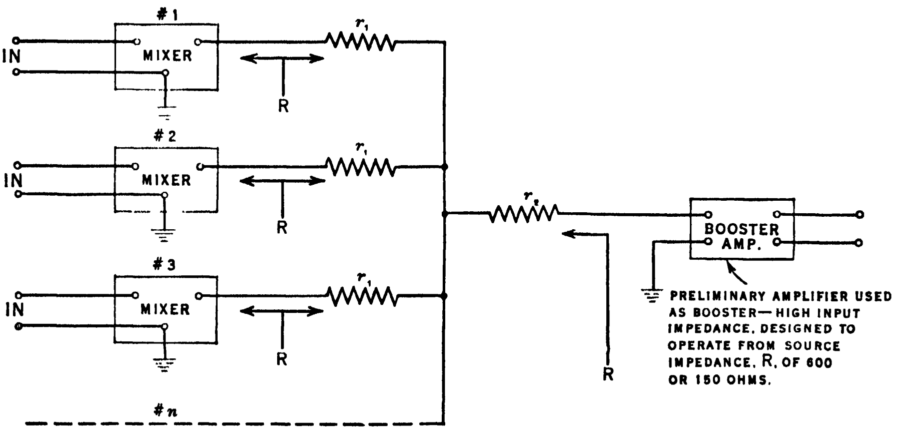
NUMBER OF CHANNELS, n	NETWORK LOSS $=20 \log_{10} n$ DB	VALUE OF BUILDING-OUT RESISTORS $r=\frac{R(n-1)}{n+1}$	
		R = 150 OHMS	R = 600 OHMS
2	6.0 DB	50 OHMS	200 OHMS
3	9.5	75	300
4	12.0	90	360
5	14.0	100	400
6	15.6	107	429
7	16.9	112	450
8	18.1	117	466

Fig. 9–42. A mixer matching-network for use between like impedances.



NUMBER OF CHANNELS, n	NETWORK LOSS $=10 \log_{10} (2n-1)$ DB	MATCHING TRANSFORMER PRIMARY IMPEDANCE Z $= \frac{R(2n-1)}{n^2}$ DB		VALUE OF BUILDING - OUT RESISTOR r $= \frac{R(n-1)}{n}$	
		R = 150Ω	R = 600Ω	R = 150Ω	R = 600Ω
2	4.8 DB	112 OHMS	450 OHMS	75 OHMS	300 OHMS
3	7.0	83	333	100	400
4	8.4	66	262	112	450
5	9.5	54	216	120	480
6	10.4	46	183	125	500
7	11.1	40	159	129	514
0	11.8	35	141	131	525

FIG. 9–43. The minimum loss mixer matching-network.



PRELIMINARY AMPLIFIER USED AS BOOSTER—HIGH INPUT IMPEDANCE, DESIGNED TO OPERATE FROM SOURCE IMPEDANCE, R, OF 600 OR 150 OHMS.

NUMBER OF CHANNELS, n	NETWORK LOSS $=20 \log_{10} n$ DB	VALUE OF BUILDING - OUT RESISTORS WHEN R = 150 Ω		VALUE OF BUILDING - OUT RESISTORS WHEN R = 600 Ω	
		r_1	r_2	r_1	r_2
2	6.0 DB	0 OHMS	75 OHMS	0 OHMS	300 OHMS
3	9.5	50	83	200	334
4	12.0	75	94	300	375
5	14.0	90	102	360	408
6	15.6	100	108	400	433
7	16.9	107	113	429	453
8	18.1	112.5	117	450	469

FIG. 9–44. Mixer matching-network for use in special case where preliminary amplifier is used as booster amplifier.

tings of the mixer controls and the master volume control, as well as additional attenuation introduced by the mixer matching network and insertion loss of ladder volume controls, if used, the program level at the output of the master volume control is very low. In order to increase this level to a value suitable for transmission, a program amplifier is employed. Program amplifiers in common use provide a gain of 50 to 70 db and have had their input and output impedances standardized at 150 and 600 ohms for broadcast work. Inasmuch as the standard transmission level from studios is + 8 *vu* and a 6-db isolating pad is used following the program amplifier, they are usually operated at an output level of + 14 *vu*. Good amplifier design requires that an amplifier be capable of a sine-wave output 10 db greater than the normal operating level to accommodate program peaks; therefore the program amplifier must deliver an output of + 24 dbm (about 250 milliwatts) without excessive distortion.

9-25. RCA BA-3A Program Amplifier—The type BA-3A program amplifier is a three-stage, resistance-capacitance coupled unit of the plug-in type, incorporating a self-contained power supply. By suitable arrangement of the input connections, this unit can be used as a line amplifier, program amplifier, or high-level isolation amplifier. A dual volume control is employed, which simultaneously controls the gain of the first and second stages.

9-25a. Technical Data

1. *Power supply:* 100 to 130 volts, 50 to 60 cps, 55 watts.

2. *Tubes:* 2 RCA 1620; 1 RCA 1622; 1 RCA 5Y3 GT/G.

3. *Source impedance:* 600-ohm or 250-ohm source.

4. *Input impedance:* Matching—550 ohms; bridging—20,000 ohms.

5. *Rated output level and distortion:* + 30 dbm with 0.5 percent total rms distortion from 50 cps to 15,000 cps; + 30 dbm with 1.0 percent total rms distortion from 30 cps to 15,000 cps.

6. *Gain:* With gain control at maximum: 65.5 db when operating from a 600-ohm source into a 600-ohm load; 27.5 db when operating from bridging input into a 600-ohm load.

7. *Frequency response:* ± 1 db from 30 cps to 15,000 cps.

8. *Noise level:* The total noise level of the amplifier measured with a 600-ohm resistance across the input terminals is 82 db or more below the rated output level of the amplifier with volume control in the maximum position.

9. *Isolation:* 90 db (with matching input).

9-25b. Circuit—An input transformer, tapped for use with a 600-ohm or a 250-ohm source, supplies the signal to the grid of the first-stage tube. Resistance-capacitance coupling is used between the first and second stages and between the second and third stages. A dual-potentiometer type gain control is a feature of the circuit. One section of this potentiometer is connected in the grid circuit of the first-stage tube while the other section is connected in the grid circuit of the second-stage tube. An output transformer, with a tapped secondary

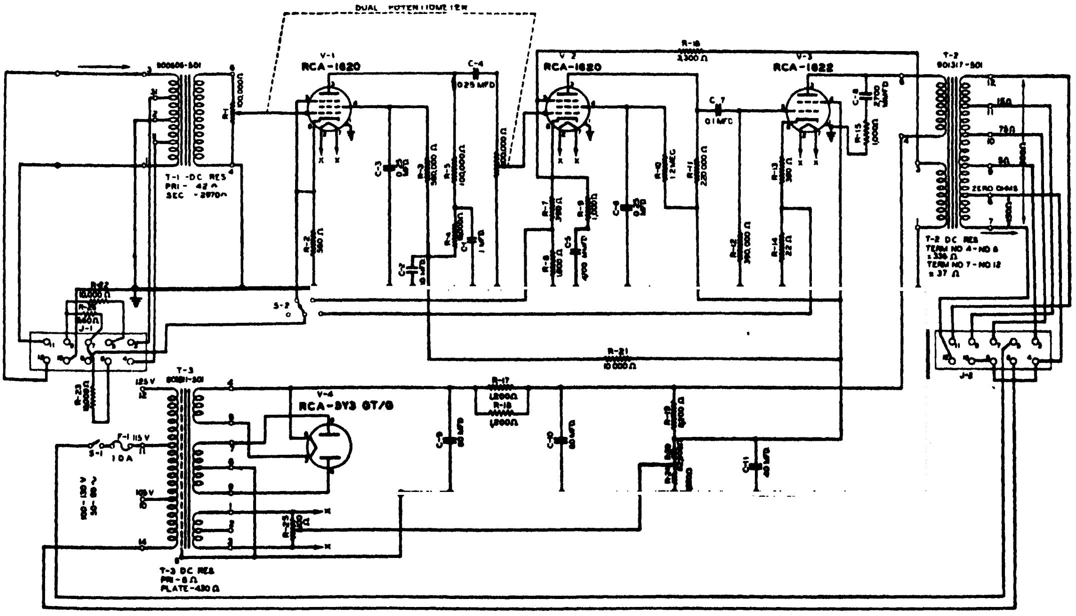


FIG. 9-45. Schematic diagram of RCA BA-3A program amplifier. (Courtesy RCA.)

winding, couples the third-stage tube to a balanced 600-ohm line or to a variety of other load impedances.

Inverse feedback from a tertiary winding on the output transformer to the cathode of the second-stage tube is included to reduce distortion, improve the frequency response, improve the output regulation and reduce instability caused by fluctuations in the a-c supply voltage and small variations in the characteristics of the tube used.

A hum-adjustment potentiometer; marked HUM, is located on the top of the chassis between the rectifier and the output tube. A screwdriver slot is provided in the potentiometer shaft for adjusting the hum and noise level in the amplifier output circuit to a minimum.

A four-position rotary switch is mounted on the front panel of the amplifier chassis. This switch is designed to be used in conjunction with a metering panel to indicate the cathode current of the individual tubes. A meter having an internal resistance of at least 20,000 ohms-per-volt may be used.

The self-contained power supply consists of a power transformer and a high-vacuum rectifier tube followed by a resistance-capacitance type filter. The electrolytic condensers in the filter circuit are of the plug-in type. A fuse holder is conveniently located on the top of the amplifier chassis near the rectifier tube. A glass-type fuse having a rating of 1 amp is used.

9–25c. Installation—All connections to the amplifier enter the unit through the two 10-prong plugs mounted on the rear panel of the chassis. The input plug is to the left (as viewed from the front of the amplifier) and the output plug is to the right directly behind the power transformer. Two identical 10-prong sockets, designed to mate with the amplifier connection plugs, are included in the kit which is supplied with each amplifier.

All audio leads should be shielded twisted-pair copper wire. All joints should be securely soldered. To prevent undesirable noise pick-up and cross-talk, the shielding of the lines to the input terminals of the amplifier should be covered with a cotton braid or other suitable insulation and the shielding should be grounded only at the amplifier (point of lowest level). Make sure that the shields are electrically continuous. Do not run the audio-input leads adjacent to, or laced in with, a-c or high-level audio lines. If the input circuits run in conduit or duct which may be subject to moisture a type of wiring having a natural or synthetic rubber covering over the shield should be used.

The amplifier is factory-wired for matching operation from a 600-ohm or a 250-ohm balanced source. Wire the incoming line to the terminals of the input-connection socket (furnished with the adapter kit) as follows:

1. For operation from a 600-ohm balanced source, connect the line to socket terminals 11 and 12.
2. For operation from a 250-ohm balanced source, connect the line to socket terminals 3 and 4.

When the input circuit operates from an unbalanced source, it will be necessary to disconnect the ground connection on the center-tap of the input-transformer primary winding. To do this, remove the jumper-connecting terminals 2 and 4 on the input transformer (T–1). Connect the incoming line as follows:

1. For operation from a 600-ohm unbalanced source connect the line to terminals 11 and 12 of the input connection socket. Make sure that the grounded side of the line connects to terminal 11.
2. For operation from a 250-ohm unbalanced source, connect the line to terminals 3 and 4 of the input connection socket. Make sure that the grounded side of the line connects to terminal 4.

A built-in pad is provided which is connected ahead of the input transformer when the amplifier is to be used with bridging input. To connect this pad into the circuit, install two jumpers on the input-connection socket: one across terminals 9 and 11, and one across terminals 7 and 12. Connect terminals 5 and 6 of the input connection socket across the line to be bridged.

The type BA–3A program amplifier is designed for operation into a variety of load impedances. The secondary winding of the output transformer (T–2) is provided with a number of taps which are brought out to the terminals of the connection plug (J–2) mounted on the rear of the amplifier chassis (directly behind the power transformer). The center tap of the output-transformer secondary winding (terminal 8 on the output transformer) is connected to terminals 4, 8 and 10 of the connection plug J–2. When the amplifier is operating into a 600-ohm balanced load, this tap should be grounded. Connection to the plug (J–2) is made by means of one of the mating sockets supplied with each amplifier. The following table shows line connections for loads of various impedance:

Load Impedance (ohms)	Socket Terminals
600 (balanced)	12 and 11
250 (unbalanced)	12 and 9
225	12 and 7
210	12 and 3
150	12 and 4
100	11 and 3
90	11 and 7
70	11 and 9
15	4 and 9
7.5	4 and 7
5	4 and 3
2.6	9 and 3
1.3	9 and 7

Connect the a-c power supply for the amplifier to terminals 5 and 6 of the output connection socket.

Refer to J–2, Figure 9–45. To insure a low hum level the a-c supply circuit should be shielded and the shield grounded. The amplifier is factory-wired with the power transformer connected for operation from a 115-volt a-c power supply line. If the line voltage is normally 120 volts or higher, disconnect the red and black wire connected to terminal 11 on the power transformer, T–3, and connect this wire to terminal number 12. If the line voltage is normally 110 volts or lower, disconnect the red and black wire and connect it to terminal 10 on T–3. Make sure that these connections are securely soldered.

The four-position rotary switch mounted on the front panel of the amplifier chassis is designed to be used in conjunction with the type 15–D metering panel to conveniently check the operation of the individual tubes. Circuit arrangement is such that, with the tubes operating normally, the meter will read approximately 1 volt. When this panel is not available, any suitable voltmeter can be used having an internal resistance of 20,000 ohms-per-volt or higher. Connect the positive terminal of the meter to terminal 8 and the negative terminal of the meter to terminal 10 on the input connection socket, J–1.

Four sockets are provided on the chassis for the plug-in type capacitors. Condenser size and voltage rating are stenciled on the chassis adjacent to the sockets. Plug the condensers into the correct sockets, making sure that the markings on the condenser cans correspond to the stenciled ratings on the chassis.

9–25d. Frequency Compensation—Under certain conditions, it may be desirable to provide additional gain at either the high-frequency or the low-frequency end of the audio range. Figure 9–46 and Figure 9–47 show graphically the amount of increase that may be expected, while Figure 9–48 illustrates the result of applying both high-frequency and low-frequency compensation in the same amplifier.

1. *Increasing High-frequency Gain.* Three curves are shown in Figure 9–46, numbered 1, 2, and 3. These curves illustrate the frequency characteristics of the amplifier after alterations are completed to increase the high-frequency response by approximately one, two and three decibels at 10,000 cycles. To make these alterations proceed as follows:

1. To obtain a frequency response curve similar to number 1, replace the .0047-μf condenser marked C–5 in Figure 9–45 with one having a value of .0065 μf. Refer to Figure 9–49.
2. To obtain a frequency response curve similar to number 2, replace the .0047-μf condenser marked C–5 in Figure 9–45 with one having a value of .0086 μf. Refer to Figure 9–49.
3. To obtain a frequency response curve similar to number 3, replace the .0047-μf condenser marked C–5 in Figure 9–45 with one having a value of .0112 μf. Refer to Figure 9–49.

2. *Increasing Low-frequency Gain.* The frequency response in the low-frequency region can be increased approximately 1½, 2½ and 3½ decibels at 30 cycles by making the alterations described below. The frequency response curves resulting from these changes are illustrated in Figure 9–47.

1. To obtain a frequency response curve similar to number 1, replace the 0.25-μf condenser marked C–4 in Figure 9–45 with one having a value of 0.03 μf and add the resistor and condenser marked X and Y as shown in Figure 9–49.
2. To obtain a frequency response curve similar to number 2, replace the 0.25-μf condenser marked C–4 in Figure 9–45 with one having a value of 0.05 μf and add the resistor and condenser marked X and Y as shown in Figure 9–49.

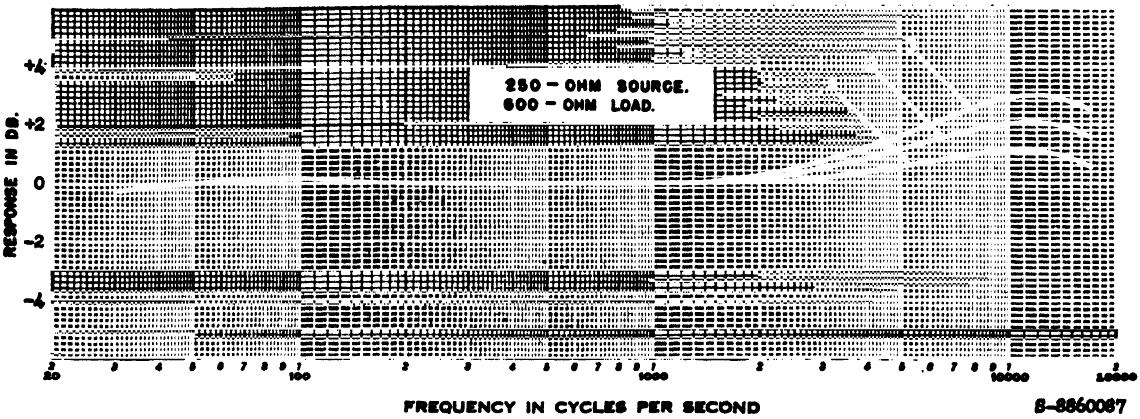


FIG. 9–46. Frequency response with high-frequency compensation. (Courtesy RCA.)

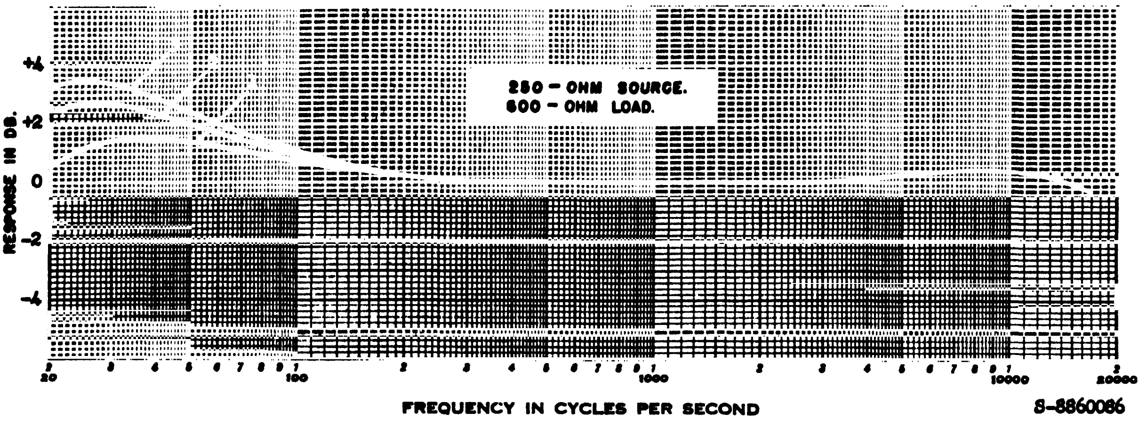


FIG. 9–47. Frequency response with low-frequency compensation. (Courtesy RCA.)

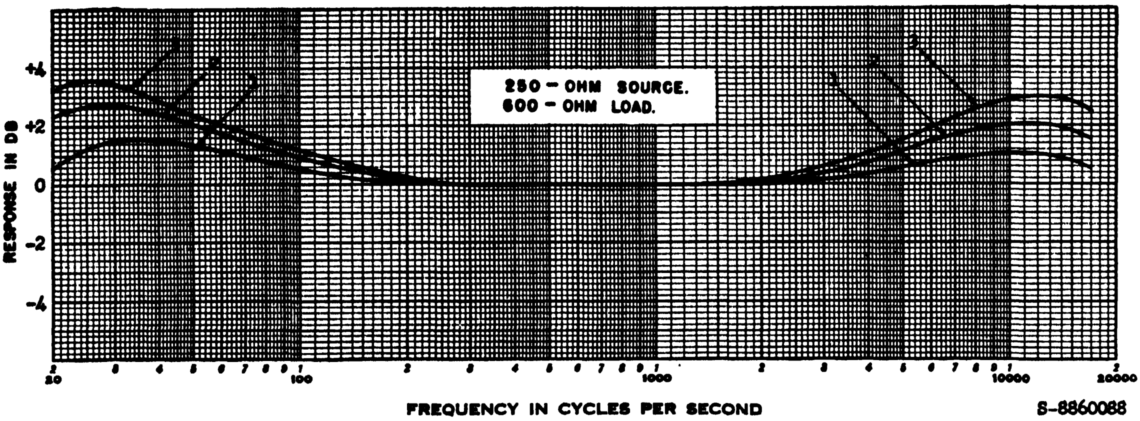


FIG. 9–48. Frequency response with high- and low-frequency compensation. (Courtesy RCA.)

3. To obtain a frequency response curve similar to number 3, replace the 0.25-μf condenser marked C–4 in Figure 9–45 with one having a value of 0.1 μf and add the resistor and condenser marked X and Y as shown in Figure 9–49.

In applications where system losses or other deficiencies require an increase in the amount of amplification at both the high-frequency and the low-frequency ends of the audio spectrum, some suitable combination can be selected and applied as described in the two preceding paragraphs. This will assist in obtaining, in a simple and effective manner, an over-all frequency response curve for the entire system which closely approaches the ideal desired.

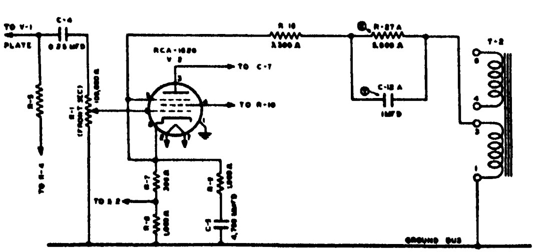


FIG. 9–49. Partial schematic diagram showing changes for compensation in RCA BA–3A amplifier. (Courtesy RCA.)

9–26. Monitoring Amplifier—A monitoring amplifier and associated loud-speaker are provided so the occupants of the control room can hear the program exactly as it is leaving the studio. Inasmuch as more than one loud-speaker may be operated from this amplifier, it is usually designed to deliver 10 to 20 watts of audio power with very low distortion. The input impedance of the monitoring amplifier is usually very high in order that it may be "bridged" across the program circuit without affecting the program level or the program circuit impedance. The output impedance is designed to match the impedance of various types of loudspeaker loads. These amplifiers usually provide an insertion gain in the vicinity of 50 db. The performance, including the response-frequency characteristics, distortion-frequency characteristics, and noise-level, should be as excellent as the state of the art permits.

9–27. RCA BA–4A Monitoring Amplifier—The type BA–4A monitoring amplifier has been designed primarily for monitoring and recording although, in an emergency, it may be used in the program channel of a transmitter. It is a four-stage, resistance-capacitance coupled amplifier with the output stage connected in push-pull. It is built on a plug-in type chassis and plug-in type electrolytic condensers are used to facilitate testing and servicing. The power supply is self-contained and all connections are made through the plugs at the rear of the chassis.

9–27a. Circuit—The input transformer is tapped for a source impedance of 250 or 30 ohms balanced-to-ground. A 1620 tube, connected as a triode, is used in the first stage and a 1620 tube, connected as a pentode, in the second stage. A potentiometer in the grid circuit of the second tube provides volume control within the unit.

The third stage is a 6SN7 dual-triode connected as a phase inverter to drive the output tubes. Inverse feedback voltage, which is obtained from a tertiary winding on the output transformer, is introduced at the cathode of the first half of this stage.

Two 1622 beam-power output tubes, connected in push-pull, are used in the output stage. The output transformer is tapped to provide a balanced output of 600 ohms and unbalanced outputs of 250, 15, 7.5, and 5 ohms.

Power for plates and screens is obtained from a 5R4GY rectifier tube used in conjunction with a power transformer and a resistance-capacitance type filter. Filament voltage is also obtained from the power transformer which is tapped for line voltages of 105, 115, and 125 volts.

9–27b. Technical Data

Four-stage High-gain Operation

1. *Power supply:* 105 to 125 volts a-c, 105 watts, 50 to 60 cps.

2. *Tubes:*

2 RCA-1620 or 2 RCA-6J7[6]	1 RCA-6SN7
2 RCA-1622 or 2 RCA-6L6[6]	1 RCA-5R4GY

3. *Source impedance:* 250- or 30-ohm source.

4. *Maximum input level:* — 27 db.[5]

5. *Output impedance:* 600 ohms balanced; 250, 15, 7.5, and 5 ohms unbalanced.

6. *Power output:* 12 watts with total rms distortion of less than 3 per cent from 50 to 7500 cps.

7. *Gain:* With volume control at maximum position: 105 ± 2 db when operating from a 250-ohm source into a 15- or 600-ohm load; 73 ± 2 db when operating with bridging volume control from a 600-ohm terminated line into a 15- or 600-ohm load.

8. *Noise level:* Total noise level measured with a 250-ohm resistor across the input terminals: — 20

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[6] When a slight increase in microphonics, hum, and distortion can be tolerated.

[5] 0 db = .001 watt.

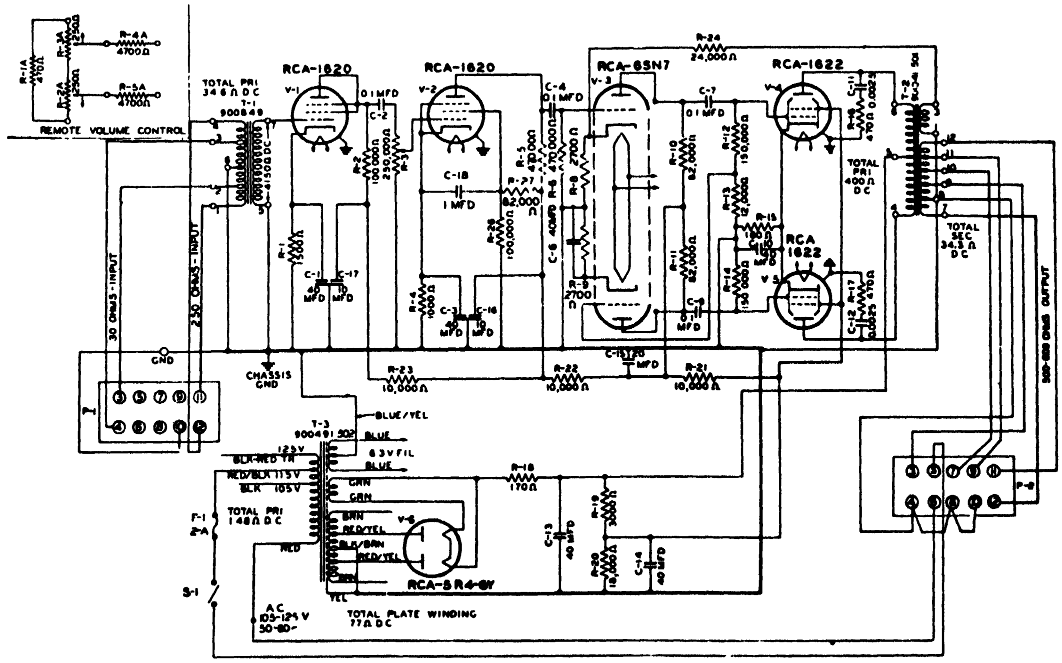


FIG. 9–50. Schematic diagram of RCA BA-4A monitoring amplifier. (Courtesy RCA.)

db[5] with volume control in maximum position; — 40 db[5] with volume control in minimum position.

9. *Frequency response:* ± 2 db from 30 to 15,000 cps. operating from a 250-ohm source into a 15-ohm load.

Three-stage Reduced-gain Operation

1. *Tubes:*

1 RCA-1620 or 1 RCA-6J7[6]	1 RCA-6SN7
2 RCA-1622 or 2 RCA-6L6[6]	1 RCA-5U4G

2. *Maximum input level:* — 24 db.[5]

3. *Power output:* Unchanged.

4. *Frequency response:* Unchanged.

5. *Gain:* With volume control at maximum position: 71 db when operating from a 250-ohm source into a 15-ohm load; 36 db when operating with bridging input into a 15-ohm load.

6. *Noise level:* Total noise level with a 250-ohm resistor across the input: — 40 db[5] with volume control in maximum position; — 60 db[5] with volume control in minimum position.

9-27c. Connections—All connections are made to the sockets which mate with the plugs on the amplifier chassis. Two sockets are supplied with the amplifier, each having 10 solder-type terminals which are numbered to correspond with the numbering of the plugs on the amplifier. Connections are made by soldering to these terminals.

1. *Audio Input Connections.* All audio input leads should be shielded cable or a shielded, twisted pair. To prevent undesirable pick-up, the leads should not run adjacent to a-c, loud-speaker field supply, or high level audio leads. When working from a 250-ohm source, connect to terminals 11 and 12 on the plug P-1. Use terminals 3 and 4 when working from a 30-ohm source.

If the input to the amplifier is from a device which has one side grounded (such as some phonograph pick-ups), it will be necessary to remove the ground connection from the center tap of the amplifier input transformer primary. In this case the lead to terminal 6 on T-1 should be disconnected and, if a ground is desired on one side of the circuit, moved to terminal 1.

When the amplifier is used to bridge a 600- or 250-ohm line, it will be necessary to use the remote volume control unit which is furnished with the amplifier.

2. *Audio Output Connections.* The secondary of the output transformer is center-tapped with the center tap connected to ground. The secondary has a number of taps which are brought out to the plug P-2. The following table gives the connections for various load impedances:

Load Impedance	Plug Terminal Connections
600 ohms balanced	11 and 12
15 ohms unbalanced	9 and 10
7.5 ohms unbalanced	7 and 8
5 ohms unbalanced	4 and 3

Output connections are made by soldering to the indicated terminals on the amplifier output socket.

3. *A-c Power Connections.* The a-c power connections are made to terminals 5 and 6 on the amplifier output plug P-2. The power transformer is normally connected for a line voltage of 115 volts.

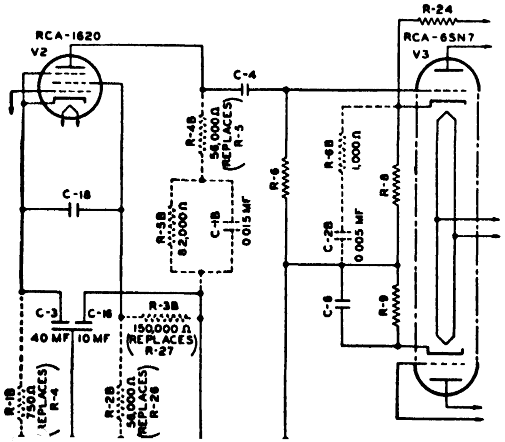
9-27d. Frequency Compensation—In certain applications, it may be desirable to provide additional gain at either the high-frequency or the low-frequency end of the audio range. This may be accomplished by the installation of resistance-capacitance networks for which a kit of parts is supplied with the amplifier.

1. *To Increase High-frequency Gain.* To increase the gain in the high frequency region, proceed as follows:

a. Connect resistor R-6B (1,000 ohms) across terminal 2 and terminal 4 on the terminal board TB-5.

b. Connect condenser C-2B (0.005 μf) between terminal 4 on the terminal board TB-5 and the ground bus.

These operations connect resistor R-6B and condenser C-2B in series from the cathode of the driver stage tube to ground (see Figure 9-51). The portion of the amplifier frequency response curve from 1000 to 15,000 cycles will now be as shown in Figure 9-52 and the portion from 30 to 1000 cycles will remain substantially flat.



PARTS TO BE ADDED AND CHANGED INDICATED BY DOTTED LINES

FIG. 9-51. Modifications of RCA BA-4A amplifier for frequency compensation. (Courtesy RCA.)

2. *To Increase Low-frequency Gain.* To increase the gain in the low-frequency region, the following changes should be made:

a. Remove resistor R-5 and connect resistor R-4B (56,000 ohms) from terminal 3 of the tube V-2 to terminal 1 on terminal board TB-1. (Terminal 1 was formerly blank.)

b. Remove resistor R–27 and replace it with resistor R–3B (150,000 ohms), connecting it from terminal 4 on the tube V–2 to terminal 2 on the terminal board TB–1.
c. Connect condenser C–1B (.015 μf) and resistor R–5B (82,000 ohms) in parallel across terminals 1 and 2 on terminal board TB–1.
d. Remove resistor R–26 and replace it with resistor R–2B (56,000 ohms), connecting it from terminal 4 on the tube V–2 to the ground bus.
e. Remove resistor R–4 and replace it with resistor R–1B (750 ohms), connecting it from terminal 4 on condenser C–16 to the ground bus.

When these changes have been made, the portion of the frequency response curve between 20 and 1000 cycles will be as shown in Figure 9–52 and the portion from 1000 to 15,000 cycles will remain substantially flat. It is important to remember that when the power output level at 60 cycles is 12 watts, the power output level between 1000 and 15,000 cycles is only 3.8 watts. This means that when the alterations outlined above have been made, the effective power output rating of the amplifier (except for some of the very low frequencies) actually has been reduced to 3.8 watts.

Both the high-frequency and low-frequency gain may be increased in the same amplifier, resulting in a frequency response curve as shown in Figure 9–52.

9–27e. Over-all Gain Reduction—For special applications, it may be desirable to operate the BA–4 amplifier at a lower gain. This may be done by disconnecting the second stage of the amplifier as follows:

1. Remove the grid lead from the grid cap of the second stage 1620 tube (V–2) and remove the tube from its socket.
2. Tape the clip on the end of the grid lead to prevent a short circuit.
3. Disconnect condenser C–4 from the terminal 1 on the third stage 1620 tube (V–3) by unsoldering the condenser lead at the tube socket.
4. Connect a suitable length of wire from terminal 2 on the variable resistor R–3 to terminal 1 on the third stage 6SN7 tube.

These operations disconnect the second stage of the amplifier and connect the output of the first stage to the grid of the third stage. The unit will now operate as a three-stage amplifier with the same characteristics as the normal four-stage amplifier except as noted under *Technical data for three-stage operation* (p. 298).

9–27f. Remote Volume Control—The MI-11274–A volume control is designed to provide a high-resistance bridging input circuit for connection between any low-impedance source and the 250-ohm input terminals of an amplifier.

This control consists of a 250-ohm dual potentiometer, a 470-ohm resistor, two 4700-ohm resistors, and a terminal board assembled as shown in Figure 9–53. The control is designed for panel mounting.

The use of one of these units makes it possible to bridge program material conveniently from any program bus or other low impedance terminated line without disturbing the operating characteristics of the line.

9–28. Langevin Type 117–A Amplifier—The type 117–A is a small, plug-in, two-stage, push-pull, fixed-gain unit intended for use as either a program

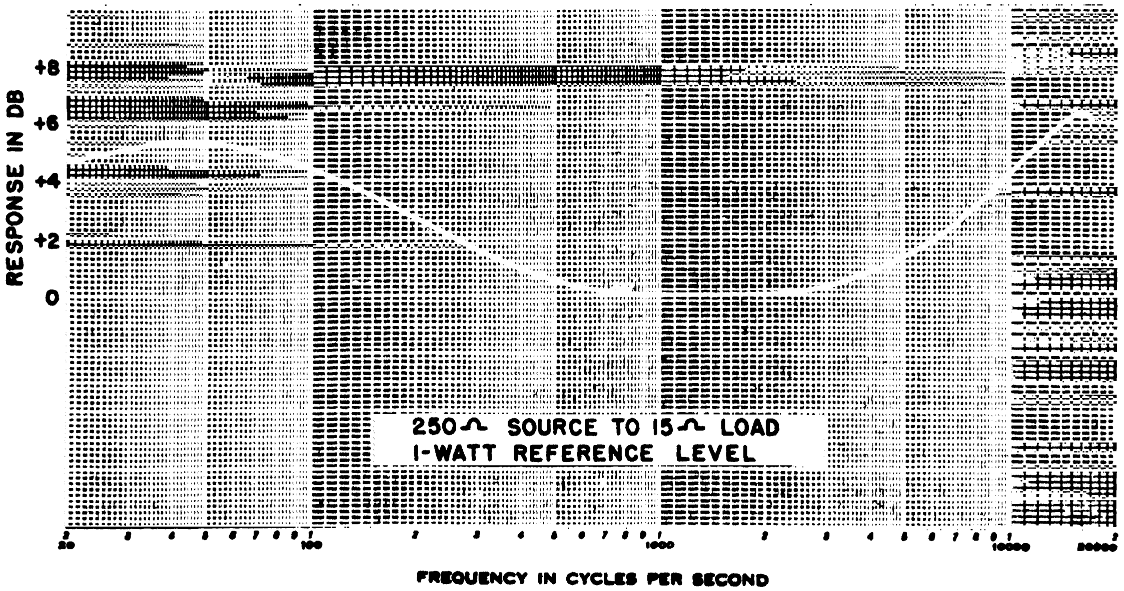


FIG. 9–52. Frequency response of RCA BA-4A amplifier with compensation. (Courtesy RCA.)

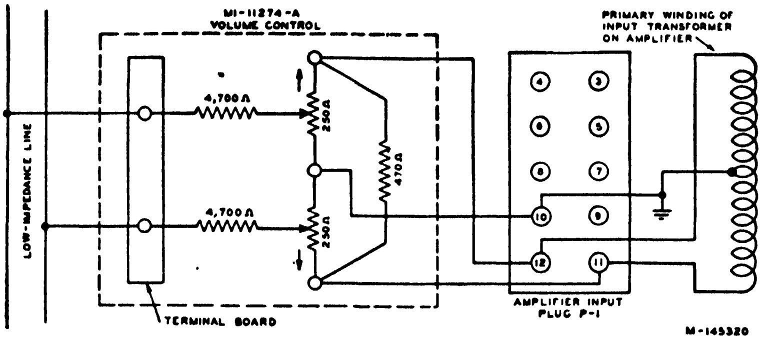


FIG. 9-53. Remote volume control for RCA BA-4A amplifier. (Courtesy RCA.)

or monitor amplifier in broadcast audio facilities, recording facilities, or sound systems. The use of one amplifier type to perform both functions makes possible an extremely flexible installation.

FIG. 9-54. Langevin type 117A program or monitor amplifier.

9-28a. Technical Data

1. *Gain:* 50 db.

2. *Input source impedance:* 30/150/250/600 ohms. Center taps are available when strapped for 150 or 600 ohms.

3. *Output load impedance:* 150 or 600 ohms. Center tap is available when strapped for 600 ohms.

4. *Output power:* + 30 dbm (1 watt) with less than 0.5 percent rms total harmonic distortion over the range 50 to 15,000 cps and less than 1 percent total harmonic distortion over the range 30 to 15,000 cps. As a monitor amplifier, + 39 dbm (8 watts) with less than 1 percent total rms harmonic distortion over the range 50 to 15,000 cps.

5. *Output noise:* Unweighted, equivalent to an input signal of — 110 to — 114 dbm, depending upon tubes, over the frequency band 50 to 15,000 cps.

6. *Frequency characteristics:* ± 1 db over the frequency range 30 to 15,000 cps.

7. *External power requirements:* Filament: 6.3 volts a.c. at 1.5 amp. Plate: 300 volts d.c. at 70 ma.

8. *Tube complement:* Two 1620's, two 6V6GT's.

9. *Dimensions:* Length 10 inches, width 3¼ inches, height 5½ inches, weight 6¼ pounds.

9-28b. Connections

Plug Pin Nos.	Circuit
1–2	Input*
3	Chassis ground
4–6	Output†
5	Tube current meter (if metering push buttons used)
7	Tube current meter (positive) VT-1
8	Tube current meter (positive) VT-3
9	Tube current meter (positive) VT-2
10	Tube current meter (positive) VT-4
11–12	Filament 6.3 volts a.c. 1.5 amp
13	B— and meter (negative)
14	B+ 300 volts d.c.

* On unbalanced input circuits, the grounded side should be connected to pin 1.

† On unbalanced output circuits, the grounded side should be connected to pin 6.

9-28c. Metering Circuits—Metering circuits are designed to measure the cathode current of the individual tubes expressed as a percentage of a normal tube, using a meter having a 200 micro-ampere movement. A series resistor should be added so that the total resistance of the meter and resistor is 1000 ohms. The meter scale should be calibrated so that nominal cathode current (100 percent) will read at 75-percent of full scale.

The amplifier is supplied with the metering connections of the individual tubes brought out to pins on the plug for use with an external meter switch. However, provision has been made for push button meter switches in the handle end of the chassis if it is desired to meter the tubes at the amplifier.

9-28d. Grounding—Connect the main ground to pin 3 on the plug receptacle. Ground the negative side of the plate supply in the following manner: When only one amplifier is being used, strap pin 13 to pin 3. When several amplifiers are used in a system, and obtain plate power from a common source, apply the ground at only one point in the system.

The center tap of the filament supply should be grounded. In some cases, however, it may be necessary to apply positive bias to the filament center tap with respect to ground, in order to reduce hum caused by filament to cathode leakage. In this event, a resistor can be connected across the plate voltage supply so that a portion of the plate voltage, 6 to 12 volts, can be tapped off and fed to the filament center tap.

9–28e. Impedance—The 117–A amplifier, as shipped, is connected to work from a source impedance of 600 ohms and into a load impedance of 600 ohms. If other impedances are desired, the amplifier may be restrapped according to the table on Figure 9–55. Strapping for the input is accomplished on the terminal strip; for the output on the output transformer.

Center taps are available on the input of the 117–A amplifier when the unit is strapped for 150 or 600 ohms, and on the output when strapped for 600 ohms. The input center tap can be grounded on the terminal strip. In order to ground the output center tap, run an additional wire from a ground point to the output transformer terminals.

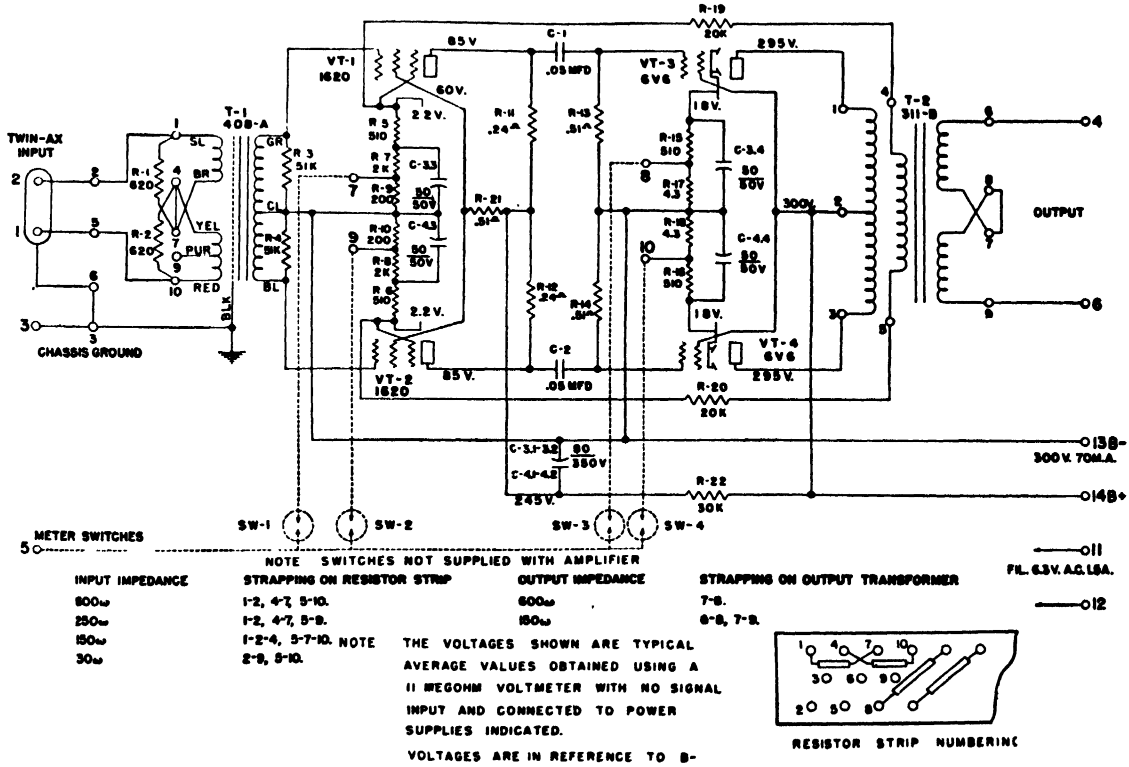
9–28f. Reduced Plate Voltage—When the 117–A amplifier is used as a program amplifier, the plate voltage may be reduced to 275 volts with a cu rent drain of approximately 65 ma without appreciably reducing the output power—thus prolonging tube life.

9–28g. Tube Substitution—In an emergency, if a 1620 vacuum tube is not available, a 6J7 tube can be substituted. This substitution may result in an increase in output noise level and tube microphonics.

9–29. Monitoring Loud-speaker—The finest available type of loudspeaker should be employed for monitoring radio programs. Desirable features for such units include:

1. Essentially uniform frequency characteristics over entire audible range.
2. Good efficiency, to reduce the power required from the driving amplifier.
3. Low values of harmonic and intermodulation distortion.
4. Wide angle of coverage at high frequencies.

The monitoring loud-speaker should preferably be mounted in a position directly above the control room window set at such an angle that it directs the sound to persons seated in their normal operating positions. In this position, the sound from the



INPUT IMPEDANCE	STRAPPING ON RESISTOR STRIP	OUTPUT IMPEDANCE	STRAPPING ON OUTPUT TRANSFORMER
600ω	1-2, 4-7, 5-10.	600ω	7-8.
250ω	1-2, 4-7, 5-9.	150ω	6-8, 7-9.
150ω	1-2-4, 5-7-10.		
30ω	2-9, 5-10.		

NOTE THE VOLTAGES SHOWN ARE TYPICAL AVERAGE VALUES OBTAINED USING A 11 MEGOHM VOLTMETER WITH NO SIGNAL INPUT AND CONNECTED TO POWER SUPPLIES INDICATED.

VOLTAGES ARE IN REFERENCE TO B-

Fig. 9–55. Schematic diagram of Langevin 117A amplifier.

loud-speaker comes from the same direction as the actual performers in the studio, which is desirable and would not be the case if the loud-speaker were mounted on a side or rear wall of the control room. Many types of loud-speakers in current use have directional properties which result in a relatively narrow angle of coverage at high audio frequencies. The use of such a unit will result in unsatisfactory high-frequency reproduction to persons seated even slightly off the axis of the loud-speaker. To offset this, two loud-speakers are often employed, for example, one centered above the control room operator and another centered above the director's desk. When this is done, care must be exercised that the two loud-speakers are correctly phased.

A more desirable solution is the use of a single, dual-unit loud-speaker with a broad angle of coverage at high frequencies. Such units, when mounted at the proper height, will usually provide satisfactory high-frequency coverage for all occupants of the control room.

9–30. Line Pad—When the program line to the transmitter is fed directly from the control room, or when a line of any appreciable length is involved, a resistance attenuation network, commonly known as a pad, is inserted between the program amplifier and the line. The purpose of this pad is to isolate the output of the amplifier from the impedance variations of the line.

Figure 9–56 shows the impedance-frequency characteristics of a typical program line several miles in length. The impedance is shown with terminations of both 600 and 150 ohms at the far end. This represents the load into which an amplifier feeding program to the line would have to work if no line pad were employed. The standard volume indicator, to give an accurate reading, must be operated across a 600-ohm circuit. As the impedance of the amplifier load is not constant, but varies considerably as a function of frequency, it is customary to isolate the amplifier from the line by means of a resistance attenuation network. The ability of such a network to smooth out the impedance variations of the line, as seen by the amplifier, can be seen in Figure 9–57, which shows the impedance the amplifier faces with line pads of 6 and 10 db. This data is for the same line illustrated in Figure 9–57 with a 600-ohm termination at the far end. It will be seen that the pad of higher attenuation results in more complete isolation, but as the attenuation in the pad represents an actual loss of audio power and gain, it is common practice to employ a 6-db line pad.

9–31. Resistance Attenuation Networks—Resistance attenuation networks, or pads, as they are commonly known, are employed quite often in audio facilities. The use of a line pad to isolate the program amplifier from the impedance variations of the program line has already been discussed. The

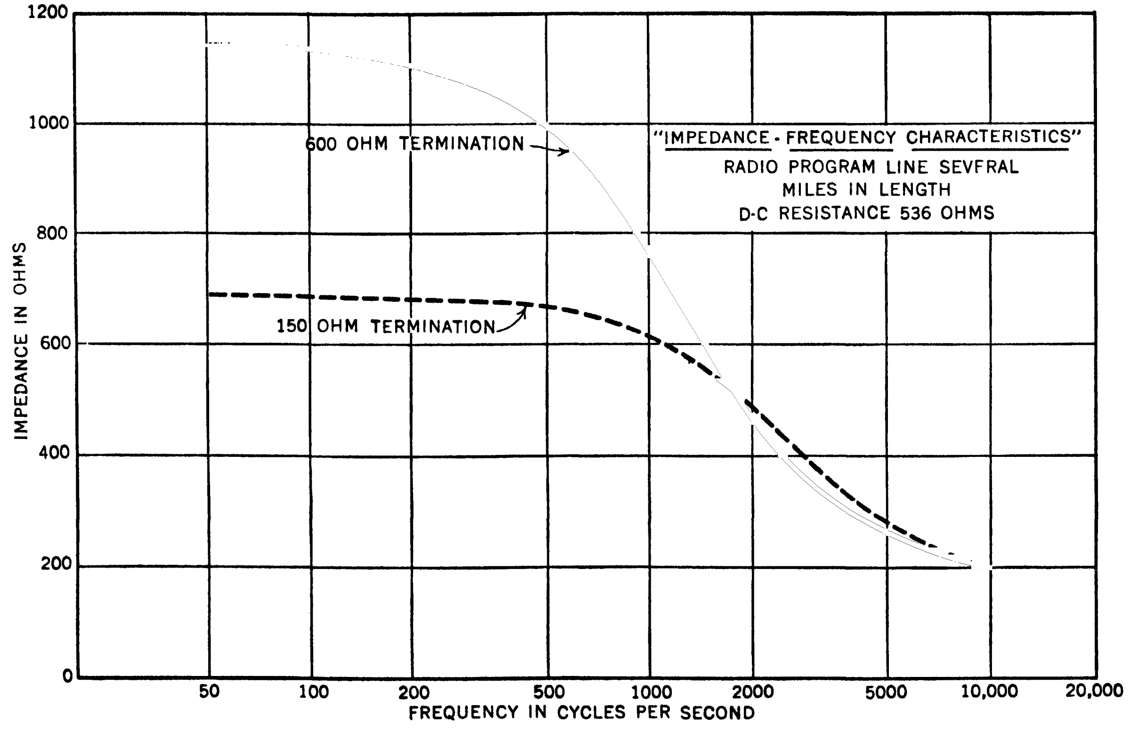


Fig. 9–56. Impedance-frequency characteristics of a typical program loop several miles in length.

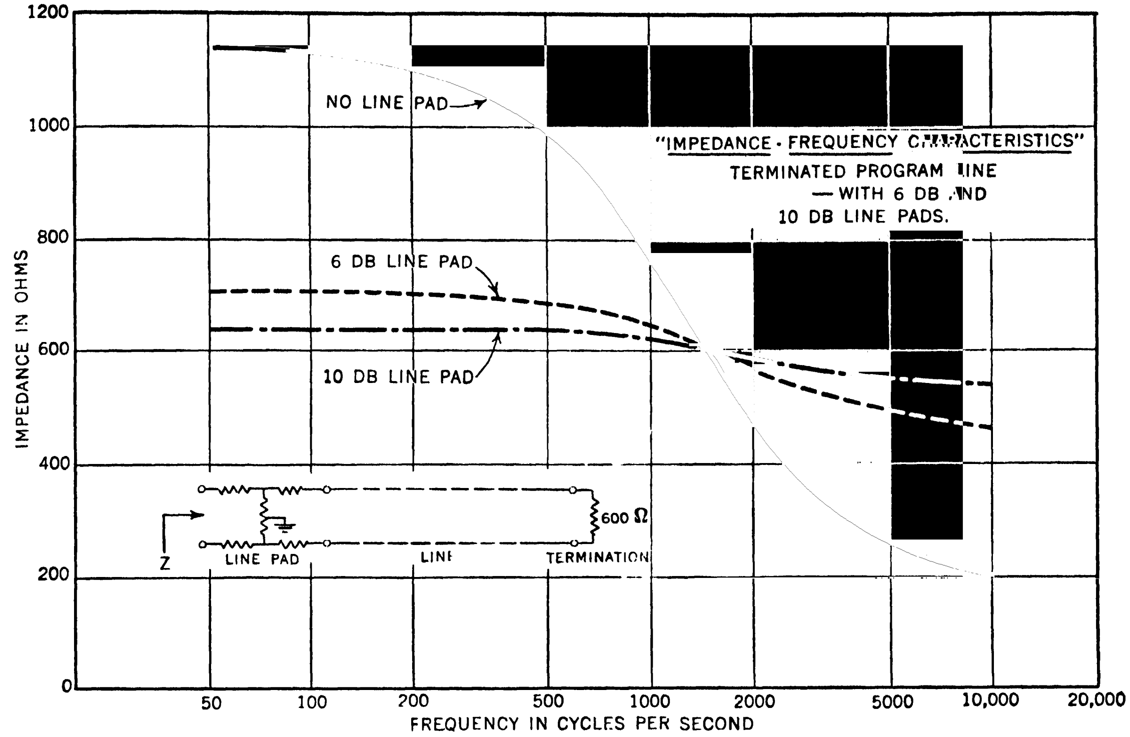


FIG. 9–57. The line pad reduces the impedance variations of the program loop, as seen by the program amplifier.

resistance attenuation network can also be employed wherever it is necessary to introduce a definite amount of loss into a circuit, as would be the case when the program level in a circuit is too high for the intended purpose. Another use of the resistance attenuation network is to achieve an impedance match between two circuits of differing impedance. A transformer could also be used for this purpose and would achieve the required impedance match with less loss than the resistance network. However, the resistance network is smaller, less expensive, its attenuation is independent of frequency, and it introduces no distortion, hum, or noise.

There are many forms of resistance attenuation networks, however, the most commonly used in audio work are the T type, H type, L type, and the U type. In addition, the split pad, or dividing network, which has one input and two or more outputs, is frequently encountered. Each of these networks is described in the following paragraphs.

9–32. The T and H Resistance Attenuation Network—The T and H networks are electrically similar, the T network being employed in the case of unbalanced-to-ground circuits, while the H network is employed in balanced-to-ground circuits. Figure 9–58 shows the arrangement of resistor elements for both types. As can be seen, these networks consist of both series and shunt resistor elements. In the case of the balanced or H type, half of the resistance value of each series element is placed in each side of the circuit. It is necessary to ground the center point of the shunt element in this case.

The values of the resistor elements can be easily calculated. There are two general cases, the first being the case where the network operates between

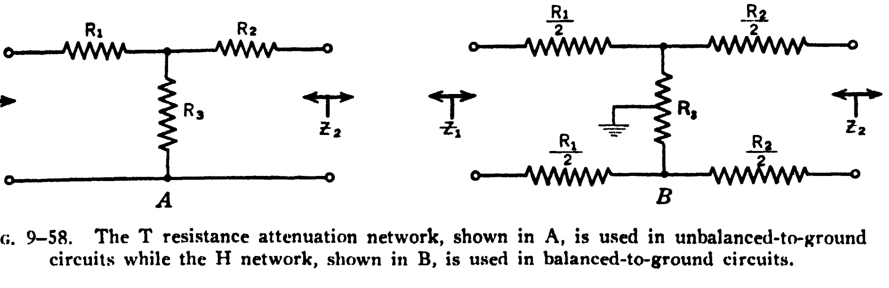


FIG. 9–58. The T resistance attenuation network, shown in A, is used in unbalanced-to-ground circuits while the H network, shown in B, is used in balanced-to-ground circuits.

equal impedances, the second where the network operates between unequal impedances.

In the first case, where the network operates between equal impedances, R_1 and R_2, as well as Z_1 and Z_2 will be equal. The values of R_1, R_2, and R_3 can be found by the following design data:

$$Z_1 = Z_2 = Z$$

$$R_1 = R_2 = Z\frac{\sqrt{N}-1}{\sqrt{N}+1}$$

$$R_3 = \frac{2Z\sqrt{N}}{N-1}$$

$$N = \text{Power Ratio}^7$$

Relation Between Power Ratios and Decibels

(The value of N may be used in calculating T and H resistance attenuation networks)

Decibels	Power Ratio (N)	Decibels	Power Ratio (N)
0.1	1.023	9.0	7.943
0.2	1.047	10	10.00
0.3	1.072	12	15.85
0.4	1.097	14	25.12
0.5	1.122	16	39.81
0.6	1.148	18	63.10
0.7	1.175	20	100.0
0.8	1.202	22	158.5
0.9	1.230	24	251.2
1.0	1.259	26	398.1
2.0	1.585	28	631.0
3.0	1.995	30	1000
4.0	2.512	32	1585
5.0	3.162	34	2512
6.0	3.981	36	3981
7.0	5.012	38	6310
8.0	6.310	40	10000

As an example, let us assume that a 10-db T resistance attenuation network, to operate between impedances of 600 ohms, is required. The resistor values would be found in the following manner (power ratio N as given in table on p. 304).

$$Z_1 = Z_2 = Z = 600 \text{ ohms}$$

$$N = 10$$

$$R_1 = R_2 = Z\frac{\sqrt{N}-1}{\sqrt{N}+1} = 600\frac{\sqrt{10}-1}{\sqrt{10}+1}$$

$$= 600\frac{2.1623}{4.1623} = 311.7 \text{ ohms}$$

$$R_3 = \frac{2Z\sqrt{N}}{N-1} = \frac{1200\sqrt{10}}{10-1}$$

$$= \frac{1200 \times 3.1623}{9} = 421.6 \text{ ohms}$$

In the second case, where the network operates between unequal impedances, the value of the resistor elements may be found by the following design data:

$$R_3 = \frac{2\sqrt{NZ_1Z_2}}{N-1}$$

$$R_1 = Z_1\left(\frac{N+1}{N-1}\right) - R_3$$

$$R_2 = Z_2\left(\frac{N+1}{N-1}\right) - R_3$$

$$N = \text{Power Ratio}^8$$

Assume that a 20 db "T" resistance attenuation network, to operate from a source impedance of 600 ohms into a load impedance of 150 ohms, is required. The resistor values for such a network would be found in the following manner (power ratio N as given in table on p. 304).

$$Z_1 = 600 \text{ ohms}$$

$$Z_2 = 150 \text{ ohms}$$

$$N = 100$$

$$R_3 = \frac{2\sqrt{NZ_1Z_2}}{N-1} = \frac{2\sqrt{100 \times 600 \times 150}}{100-1}$$

$$= \frac{2\sqrt{9000000}}{99} = 60.6 \text{ ohms}$$

$$R_1 = Z_1\left(\frac{N+1}{N-1}\right) - R_3 = 600\left(\frac{101}{99}\right) - 60.6$$

$$= 551.4 \text{ ohms}$$

$$R_3 = Z_2\left(\frac{N+1}{N-1}\right) - R_3 = 150\left(\frac{101}{99}\right) - 60.6$$

$$= 92.4 \text{ ohms}$$

9–33. The L and U Resistance Attenuation Networks—Like the T and H networks, the L and U types are also electrically similar, the L network being used in the case of unbalanced-to-ground circuits, and the U type in the case of balanced-to-ground circuits. Figure 9–59 shows the arrangement of resistor elements for both types. L and U pads represent the limiting case of T and H pads working between unequal impedances where the value of one series arm has been reduced to zero ohms. These networks therefore provide impedance matching between two circuits with the minimum loss possible in a resistance network.

L and U networks are used extensively for obtaining impedance matches between circuits of differing impedances, and also as bridging pads where the input impedance of the network is high and it is bridged across a terminated program circuit. Bridging pads are discussed later in this chapter.

The design data are the same for both types, in the case of the U network, half of the resistance

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[7] See table on p. 304.

[8] See table on p. 304.

RESISTANCE ATTENUATION NETWORK DATA FOR NETWORKS OPERATING BETWEEN EQUAL IMPEDANCES

Loss in Db	150-Ohm Network			600-Ohm Network		
	R_1 (Ohms)	R_2 (Ohms)	R_3 (Ohms)	R_1 (Ohms)	R_2 (Ohms)	R_3 (Ohms)
0.1	0.895	0.895	12551	3.58	3.58	50204
0.2	1.705	1.705	6570	6.82	6.82	26280
0.3	2.58	2.58	4365	10.32	10.32	17460
0.4	3.45	3.45	3267	13.79	13.79	13068
0.5	4.30	4.30	2616	17.20	17.20	10464
0.6	5.22	5.22	2160	20.9	20.9	8640
0.7	6.05	6.05	1857	24.2	24.2	7428
0.8	6.875	6.875	1635	27.5	27.5	6540
0.9	7.75	7.75	1447	31.0	31.0	5787
1.0	8.625	8.625	1302	34.5	34.5	5208
2.0	17.2	17.2	645.5	68.8	68.8	2582
3.0	25.7	25.7	425.75	102.7	102.7	1703
4.0	33.95	33.95	312.25	135 8	135.8	1249
5.0	42.02	42.02	246.9	168.1	168.1	987.6
6.0	49.83	49.83	200 9	199.3	199.3	803.4
7.0	57.43	57.43	171.3	229.7	229.7	685.2
8.0	64.6	64.6	141.9	258.4	258.4	567.6
9.0	71.45	71.45	121.8	285.8	285.8	487.2
10.0	78.0	78.0	105.4	312.0	312.0	421.6
12.0	89.8	89.8	80.43	359.1	359.1	321.7
14.0	100.1	100.1	62.35	400.4	400.4	249.4
16.0	108.9	108.9	48.8	435.8	435.8	195.1
18.0	116.5	116.5	38.1	465.8	465.8	152.5
20.0	122.6	122.6	30.4	490.4	490.4	121.2
22.0	127.9	127.9	23.98	511.7	511.7	95.9
24.0	132.2	132.2	19.0	528.8	528.8	76.0
26.0	135.7	135.7	15.1	542.7	542.7	60.3
28.0	138.5	138.5	11.95	554.1	554.1	47.8
30.0	140.7	140.7	9.5	563.0	563.0	37.99
32.0	142.7	142.7	7.54	570.6	570.6	30.16
34.0	144.1	144.1	5.99	576.5	576.5	23.95
36.0	145.3	145.3	4.75	581.1	581.1	18.98
38.0	146.3	146.3	3.78	585.1	585.1	15.11
40.0	147.0	147.0	3.0	588.1	588.1	12.00

value of the series element is placed in each side of the network. The resistor values can be found by means of the following design data.

$$R_1 = \sqrt{Z_1(Z_1 - Z_2)}$$

$$R_2 = \frac{Z_1 Z_2}{R_1}$$

$$\text{Loss in decibels} = 20 \log_{10} \left(\sqrt{\frac{Z_1}{Z_2}} + \sqrt{\frac{Z_1}{Z_2} - 1} \right)$$

As an example, let us assume that an L resistance attenuation network is required to match, with minimum loss, a 500-ohm source and a 250-ohm load. The resistor values would be found in the following manner.

$$Z_1 = 500 \text{ ohms}$$

$$Z_2 = 250 \text{ ohms}$$

$$R_1 = \sqrt{Z_1(Z_1 - Z_2)} = \sqrt{500(500 - 250)}$$

$$= \sqrt{125,000} = 353.5 \text{ ohms}$$

$$R_2 = \frac{Z_1 Z_2}{R_1} = \frac{125,000}{353.5} = 353.5 \text{ ohms}$$

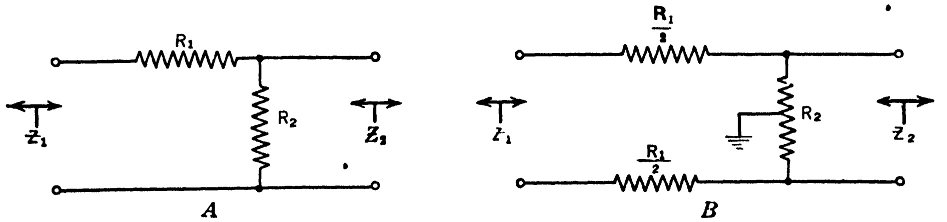

FIG. 9–59. The L pad, shown in A, is employed in unbalanced-to-ground circuits while the U pad, shown in B, is used in balanced-to-ground circuits.

$$\text{Loss in decibels} = 20 \log_{10} \sqrt{\frac{Z_1}{Z_2}} + \sqrt{\frac{Z_1}{Z_2} - 1}$$
$$= 20 \log_{10} \sqrt{2} + \sqrt{2 - 1}$$
$$= 20 \log_{10} 2.416 = 7.7 \text{ db}$$

In the example just given, the impedance ratio of the network was 500 to 250 ohms or a ratio of 2. The loss of L or U networks of other impedance ratios is given in the following table.

Impedance Ratio	Loss in db
1.2 (600/500)	3.7
1.5	5.7
2.0	7.7
2.4 (600/250)	8.8
3.0 (600/200)	10.0
4.0	11.4
5.0	12.5
6.0	13.5
8.0	14.8
10.0	15.8
12.0	16.7
16.6 (10K/600)	18.4
20.0	19.0
30.0	20.7
33.0 (20K/600)	21.2
40.0	21.7
50.0	23.0
100.0	26.0

9-34. Split Pads—A resistance network wherein the audio power of a program circuit is split, or divided, into two or more outputs, while the impedance relations are maintained properly in all branches, is often quite useful in audio systems. Such a network can be employed in reverse, that is, two or more program circuits can be combined into a single circuit. This is exactly what is done in the case of a mixer matching network.

The circuit arrangement for such a dividing, or differential,[9] network operating between equal impedances is given in Figure 9-60. The value of resistor R, as well as the loss between the input and any output, can be calculated from the following design data:

$$R = \frac{Z(n-1)}{n+1}$$
$$\text{Decibel loss} = 20 \log_{10} n$$

where n equals the number of pad output positions.

As an example, if an unbalanced-to-ground dividing network with one 600-ohm input and two 600-ohm outputs is required, the value of the three resistor elements would be found in the following manner:

$$n = 2 \text{ (2 output positions)}$$
$$R = \frac{Z(n-1)}{n+1} = \frac{600(2-1)}{2+1} = 200 \text{ ohms}$$
$$\text{Decibel loss} = 20 \log_{10} n$$
$$= 20 \log_{10} 2$$
$$= 6.02 \text{ db}$$

9-35. Line Transformers—Line transformers, commonly known as "repeat coils," are frequently employed in audio systems for terminating program lines, for impedance matching, or at points in a circuit where it is necessary to change the circuit arrangement from a balanced-to-ground to an unbalanced-to-ground condition. Line transformers for this latter purpose are shown on the two incoming line mixer channels in Figure 9-33. In this case, they properly isolate the circuit grounds of the balanced-to-ground program lines and the unbalanced-to-ground mixer controls as shown in Fig. 9-61. Should the impedance of the program lines and the mixer controls differ, for example, should the program lines have a nominal impedance of 600 ohms and the mixer controls 150 ohms, the same transformer can be employed to achieve an impedance match.

Line transformers usually have a 1 : 1 primary-to-secondary impedance ratio, but are equipped with taps to permit other impedance ratios to be obtained. The type of transformer shown in Figure 9-61, which provides an impedance ratio of 600/150:

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[9] The term "differential network" is the preferred name for this type of resistance network.

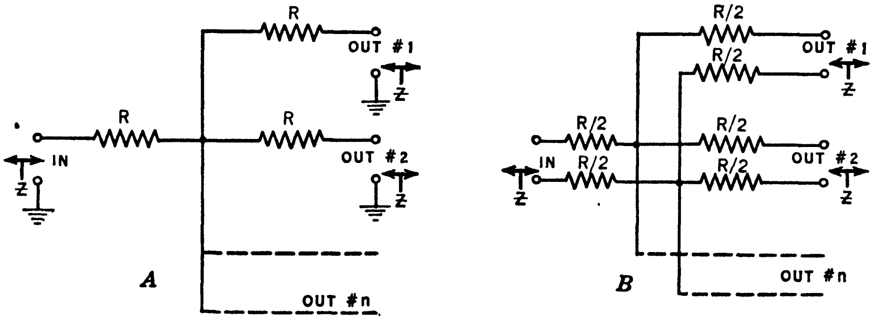

FIG. 9-60. The split pad, or dividing network, which provides any desired number of output circuits from a single input circuit. Circuit A is for use in unbalanced-to-ground circuits, while B is for use in balanced circuits.

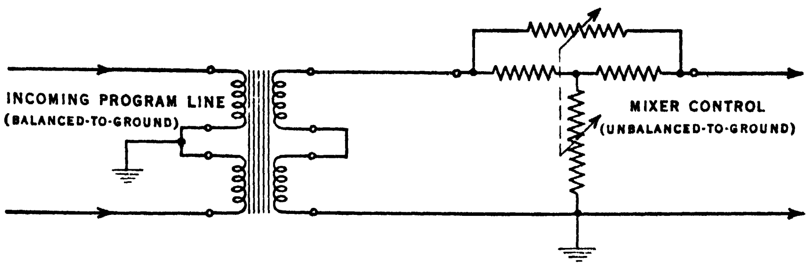

FIG. 9–61. The "repeat coil" between a balanced-to-ground program line and a one-sided-grounded mixer control properly isolates the circuit grounds. In addition, noise picked up on the program line will be largely balanced out in the primary of the transformer. An electric static shield between primary and secondary windings is desirable.

600/150 ohms, is commonly used in broadcast work. Line transformers should be well shielded, both magnetically and electrostatically, to prevent hum or noise pick-up, and should have the center tap at the exact electrical center of the winding so that noise picked up on the line will be balanced out and returned to earth through the grounded center tap.

9–36. Bridging Transformers—It is often necessary in broadcast audio facilities to employ a bridging transformer to obtain a sample of the program material from a program circuit without disturbing the impedance relations or program level in the circuit. This is often done when it is necessary to feed the program to a monitor circuit, test circuit, or a building loud-speaker system.

A bridging transformer has a high primary impedance, usually 30 to 50 times the impedance of the circuit to be bridged, and a secondary impedance of 150 and 600 ohms. It is important that building-out resistors of the correct value be included in the primary winding, otherwise, the reflected secondary impedance will not be correct. Two methods of connecting the building-out resistors in the primary winding are shown in Figure 9–62. In the case of commercially available bridging transformers, these resistors are usually included internally within the unit.

A typical bridging transformer employed in broadcast audio facilities provides a primary impedance (including building-out resistors) of 20,000 ohms, and a secondary impedance of 600 ohms. The transformer unit itself usually has an impedance ratio of 10,000/600 ohms. The total bridging impedance is built-out to 20,000 ohms by means of the building-out resistors. It is customary to take into account both the d-c resistance of both windings, as well as the impedance of the circuit being bridged, in determining the exact value of the building-out resistors.

The insertion loss of a bridging transformer is a function of the ratio of the bridging impedance Z_b, to the impedance of the circuit being bridged, Z_l. An additional loss is contributed by the building-out resistors. The total insertion loss for bridging transformers of several different impedance ratios is given below.

Impedance Ratio Z_b/Z_l	Insertion Loss* (db)
10	13.0
16.6 (10,000/600Ω)	15.2
20	16.0
30	17.8
33.3 (20,000/600Ω)	18.2
40	19.0
50	20.0
100	23.0

* In practice, a slight additional loss will be encountered because of the internal losses within the transformer.

Inasmuch as the transformer provides isolation from circuit grounds a bridging transformer may be connected across either balanced-to-ground or unbalanced-to-ground circuits. They are susceptible to hum and noise pick-up, therefore, only well shielded units, preferably with hum-bucking coil construction, should be used.

9–37. Bridging Pads—Bridging pads are often employed in place of bridging transformers. The bridging pad has the disadvantage that it produces a greater insertion loss than a bridging transformer but, on the other hand, has several advantages to

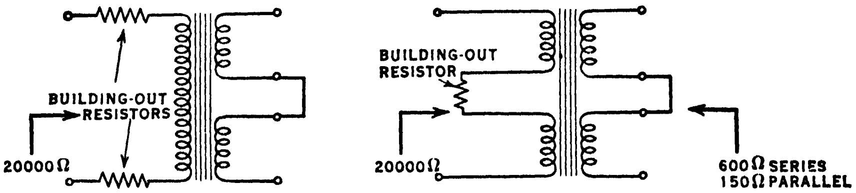

FIG. 9–62. Two arrangements of building-out resistors in bridging transformers.

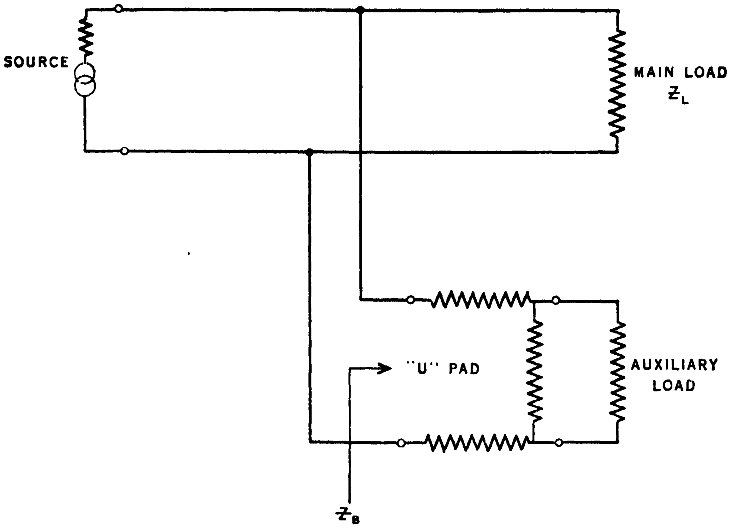

FIG. 9–63. Bridging pad employing U type network.

offset this. The bridging pad introduces no frequency discrimination, no low frequency distortion, and no hum pick-up. In addition, it is smaller in size and less expensive than the bridging transformer.

An L pad is usually employed to bridge unbalanced-to-ground circuits and the U pad to bridge balanced-to-ground circuits. Other types could be used, but the L and U types result in a minimum insertion loss. Design data for these pads are given in Section 9–33 of this chapter.

The total insertion loss of a bridging pad is the sum of the attenuation contributed by the pad, and the loss produced by the mismatch resulting from the bridging connection. The total insertion loss for bridging pads of several impedance ratios is given below.

Impedance Ratio Z_b/Z_l	Total Loss (db) (Pad Loss + Bridging Loss)
10	25.8
16.6 (10,000/600Ω)	30.6
20	32.0
30	35.5
33.3 (20,000/600Ω)	36.4
40	37.7
50	40.0
100	46.0

9–38. Radio Program Lines—Radio program lines, which are actually specially selected telephone lines, are employed to carry program material from one point to another, for example, from the studio to transmitter or from a remote pick-up point to the studios. Telephone lines are also employed to interconnect stations in different cities as, for example, in network broadcasting. Local lines between points in the same city are known as "loops"; lines from one city to another are known as "long lines."

Telephone lines, due to their distributed capacitance and inductance, act as low-pass filters and unless some means is provided for reducing the low frequencies to a value comparable to the high frequencies, frequency distortion of the program material will result, as the low frequencies will predominate. Correction of the frequency characteristics of a program line is known as *equalization*. Long lines are usually equalized by means of amplifiers, equalizers, and phase correctors, installed at frequent intervals along the line. These long lines are therefore already equalized when turned over to the radio station. Program loops, however, are usually not equalized, and it is necessary to employ the proper terminal equipment if satisfactory frequency characteristics over the audio frequency range are to be obtained.

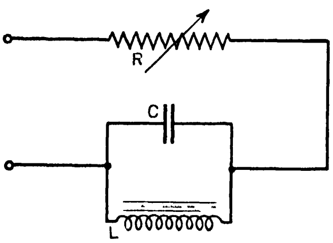

FIG. 9–64. A line equalizer. The resonant frequency of L and C is usually slightly higher than the highest frequency to be transmitted.

9–39. Line Equalizers—It is possible to correct the frequency characteristics of a program loop by means of a line equalizer such as shown in Figure 9–64. This device consists of an adjustable resistor connected in series with a parallel circuit containing capacitance and inductance, the entire network being connected across the receiving end of the line to be equalized. The equalizer is usually designed so the resonant frequency of the capacitance and inductance is slightly higher than the highest frequency to be transmitted.

The program loop is equalized by adjusting the value of *R* until the response to low and high frequencies is equal. The amount of equalization will depend upon the length of the loop; for example, a short loop will require very little equalization (the value of *R* will be high), while a long loop may require considerable equalization and very careful adjustment of the equalizer.

9–40. Western Electric 23–A Line Equalizer—The Western Electric 23A equalizer was designed for use in radio broadcasting to correct the nonuniformity of transmission in the range from 35 to 8000 cycles per second of nonloaded telephone cable circuits employed for the transmission of high-quality program material It is intended for use on program lines that are employed frequently enough to justify the permanent association of an equalizer.

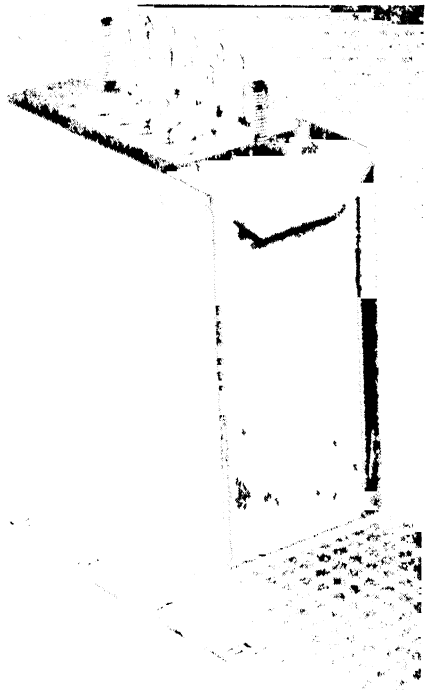

Fig. 9–65. Western Electric 23A equalizer. (Courtesy Western Electric)

The 23A equalizer is of the shunt type consisting of an inductance and a capacitance in parallel and a tapped series resistance, the value of which is determined at the time of installation from the transmission characteristic of the circuit. Seven resistance units are provided, the ends of which are brought out to numbered terminals to facilitate connections.

The resistance units are not connected. In making tests to determine the value of resistance to be employed, an external variable resistance box is used (connected between terminals 1 and 4 of the strip). When the correct value of resistance has been determined, the resistance box is removed from the circuit and the proper combination of fixed resistance connected. A total resistance of 322.5 ohms is available across terminals 3–4, which, experience has shown, is sufficient to meet practically all line conditions. The schematic shows the manner in which the resistance units are connected.

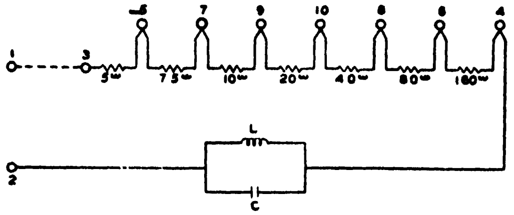

Fig. 9–66 Circuit arrangement of the Western Electric 23A equalizer. (Courtesy Western Electric)

Nonloaded cable circuits, consisting entirely of one gauge, can be equalized up to the approximate lengths given below by the use of the 23A equalizer.

FOR EQUALIZATION WITH MAXIMUM DEVIATION OF 1 DB		FOR EQUALIZATION WITH MAXIMUM DEVIATION OF 2 DB	
Gauge	Length (miles)	Gauge	Length (miles)
16	21.5	16	25
19	10	19	11.5
22	6.5	22	7

9–41. Program Loop Transmission—Figure 9–68 shows the arrangement of terminal equipment at each end of a program loop. The use of a line transformer at the receiving end of the loop, with its primary center tap grounded, is essential if line noise is to be minimized. Although not shown, a 1:1 line transformer at the transmitting end of the loop is often effective in further reducing line noise. The receiving-end line transformer is shown with an impedance ratio of 1:1. Better results are sometimes obtained on longer loops if a receiving transformer with a 1:4 impedance ratio (150:600 ohms, with 150-ohm winding facing line) is employed. This results in a better impedance match at the transmitting end, as can be seen in Figure 9–56.

Another method sometimes used on short program loops, which provides satisfactory program transmission without the use of a line equalizer, is shown in Figure 9–69. In this case 1:4 impedance-ratio line transformers are employed at each end of the loop. With this arrangement, satisfactory frequency characteristics up to a frequency of 8000

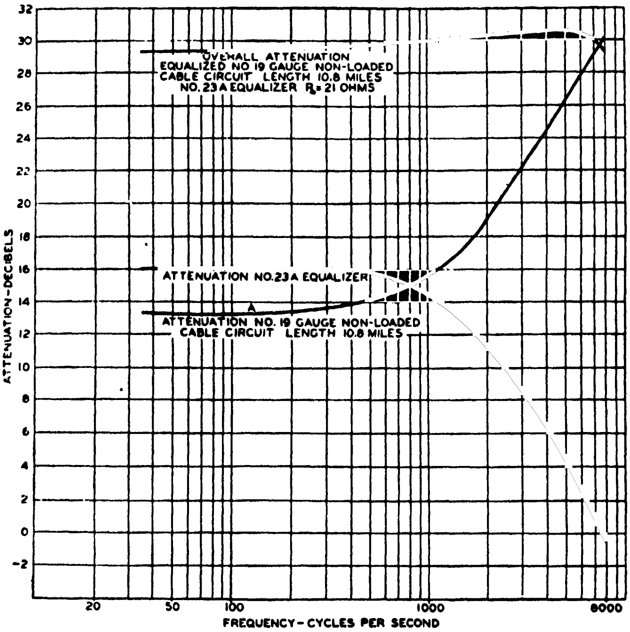

Fig. 9–67. Typical attenuation curves of 23A equalizer. (Courtesy Western Electric.)

cycles can be obtained, without equalization, on program loops of the following lengths.

Gauge	Length (miles)
16	5
19	2.3
22	1.5

In the case of loops made up of several different wire gauges, other lengths would apply.

It is often necessary to employ a single program loop which can be easily reversed when desired. Such an arrangement might be employed between two stations that exchange programs. In this case, duplicate terminal equipment should be provided at each end of the loop as shown in Figure 9–70. With this arrangement, the equalizer at one end will be disconnected, while another equalizer will be connected at the other end, when the loop is reversed. It is important that the line equalizer always be at the receiving end of the loop if noise and cross-talk are to be minimized. If desired, jacks and patchcords can be employed to reverse the loops in place of the key switch arrangement illustrated.

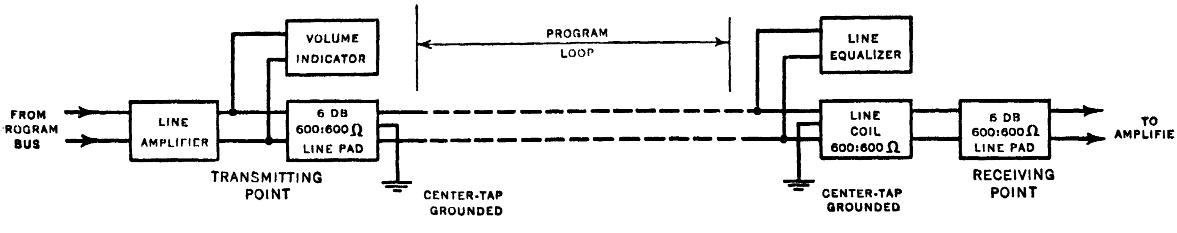

Fig. 9–68. Arrangement of terminal equipment at each end of a program loop.

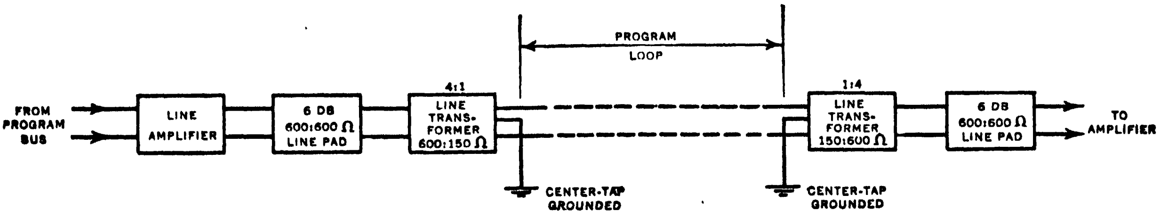

Fig. 9–69. Program loop transmission, on very short loops, without equalization.

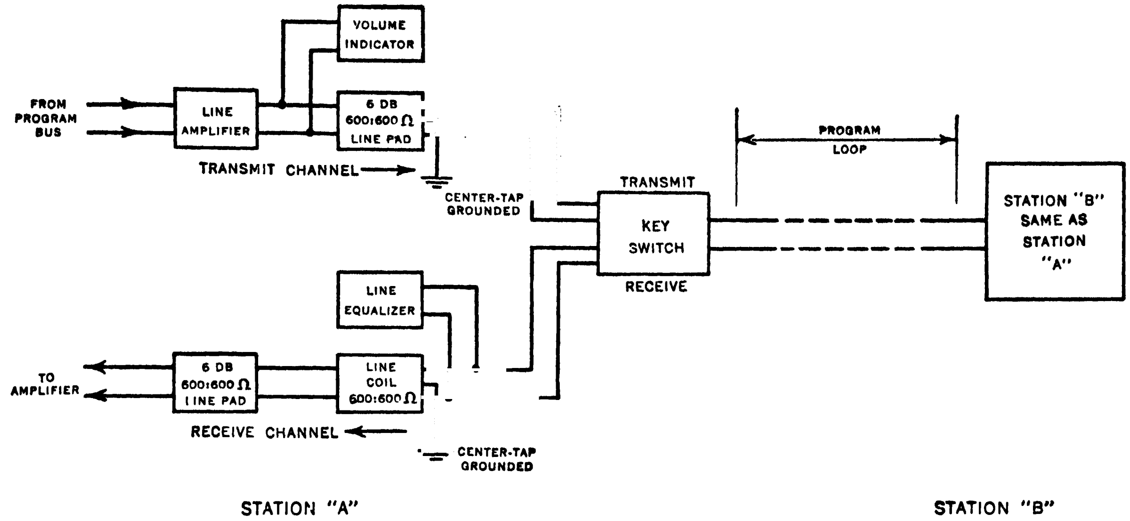

Fig. 9–70. Program loop transmission where line reversal is necessary.

9–42. Jacks and Patchcords—An audio jackfield, consisting of a bank of telephone type jacks, is often employed in broadcast audio facilities. To these jacks are connected the input and output of all important circuits and components of the system. Short jumpers between jacks, known as "normals," serve to connect the various components and circuits together to form the complete audio system.

A jackfield incorporated in an audio system provides a high degree of operational flexibility. By the use of patchcords, any of the following operations may be quickly performed.

(a) A defective component may be readily replaced by another similar unit, or may be removed completely from the circuit by patching around the unit.
(b) The program circuits may be rearranged as desired when this is necessary.
(c) Special-effect devices, such as filters or reverberation facilities, may be inserted in any desired program channel.

In addition to the operational conveniences made possible by the jackfield, maintenance of the facilities is greatly simplified, as it is possible to make direct connection to the terminals of any component of the system. Location of a defective unit is thereby greatly facilitated.

An audio jackfield resembles a telephone switchboard jackfield. Two types of plugs and jacks are currently in use: the tip, ring, and sleeve type of plug used with a single telephone jack, and the twin plug, used with pairs of telephone jacks. Although the latter type are in more common use at the present time, single plugs and jacks offer several advantages including smaller space requirement, lower cost, lower cross-talk, and impossibility of reversed plug insertion such as may occur with the twin type of plug. It is essential that the correct type of single plug be employed if satisfactory operation is to be obtained.[10]

An illustration of an audio jackfield employing the "single" type of jacks is shown in Figure 9–71. A typical "double" jack installation may be seen in Figure 9–88. The small designation card above each jack identifies the circuit to which the jack connects.

Figure 9–72 shows an audio system with the same facilities as the system of Figure 9–33 but with jacks provided at the input and output of the various units. It can be seen that substitution of equipment may be readily accomplished by means of two patchcords. For example, if one of the preliminary amplifiers should become defective, the input and output of an unused amplifier can be picked up with patchcords and patched into the circuit in place of the defective unit.

9–43. Sound Effects Filters—By proper modification of the normal response-frequency characteristic of the program channel, telephone conversations, police and airway radio circuits, and other effects can be readily simulated. This response-frequency modification is usually obtained by means of filters which are patched into the desired microphone channel. Adjustable filters have been developed especially for this purpose and are commonly known as "sound effects" filters.

An effective sound effects filter consists of a low-pass section and a high-pass section connected in cascade. The cut-off frequency of each section is independently adjustable, a choice of any one of eight frequencies (100, 250, 500, 1000, 2000, 3000,

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[10] H. A. Chinn and R. B. Monroe, "Single Jacks for Broadcast Application," *Audio Engineering*, Vol. 31, No. 6 (July 1947).

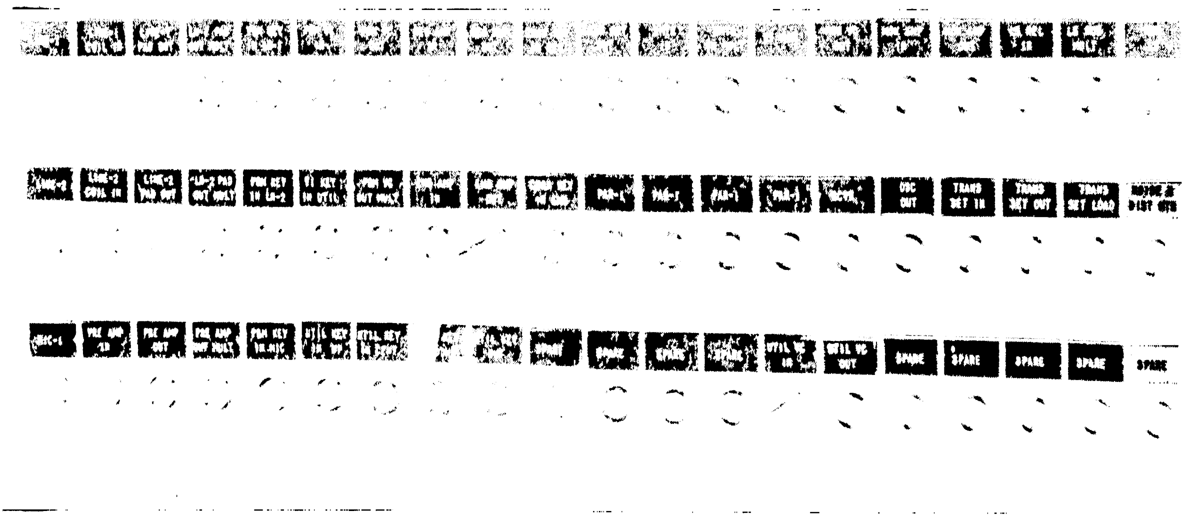

FIG 9-71 An audio jackfield consists of a bank of telephone type jacks which connect to the input and output terminals of various components of the system The jacks are "normalled" in such a manner that no patchcords are required unless special setups are desired (Courtesy CBS)

4000 and 5000 cycles) being available In addition, the individual sections may be removed entirely from the circuit The unit can therefore be used either as a high-pass, as a low-pass, or as a bandpass filter

Each filter section is a single prototype or constant-*K* section and may be either of pi or T configuration For reasons of economy it is often desirable to employ a pi-section for the low pass unit and a T-section for the high-pass unit this arrangement requiring the minimum number of inductors In the unit being described the *Q* of the coils is sufficiently high to provide attenuation at a rate of 18 db per octave until at least 60-db attenuation has been obtained The insertion loss in the pass-band is less than 1 db

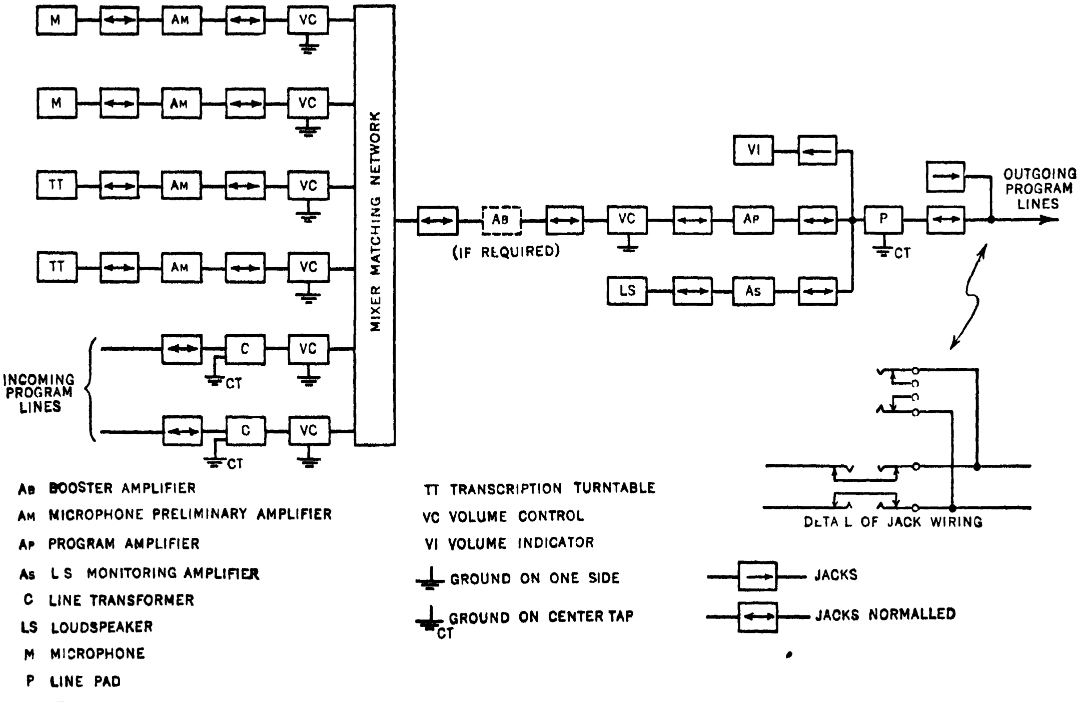

FIG 9-72 Studio audio facilities similar to those shown in Fig 9-33 but including jacks in the various circuits

To insure against switching noises during operation of the range switches, the condensers in the various sections are shunted with suitable resistors to provide a continuous discharge path. Furthermore, the switching arrangement is such that in passing from one set of contacts to the next continuity of the signal through the filter is maintained, thereby avoiding any program breaks if adjustments are made during a broadcast.

Since the filters are often used in low-level circuits (such as between the output of a preliminary amplifier and the mixer control), adequate shielding must be provided to prevent pick-up from adjacent stray electromagnetic fields. The use of hum-bucking construction in the coils also helps in this respect.

9–44. Studio Control Consoles—Thus far in this chapter, only the components employed in studio audio facilities have been considered. To illustrate how these components are assembled to form complete studio control systems, several of the studio audio consoles now in actual operation in broadcast stations throughout this country are described in the following paragraphs.

9–45. The CBS 3B Studio Control Console—The CBS 3B console, Figure 9–73, is a studio control unit designed for use in larger broadcasting studios and radio theaters of the Columbia Broadcasting System. It incorporates in a relatively small desk-like unit all the amplifying, mixing, monitoring and special-effect facilities normally required in the production of complex network radio program originations.

Two examples of departure from convention to achieve compactness are the use of single plugs and jacks in place of the more conventional twin

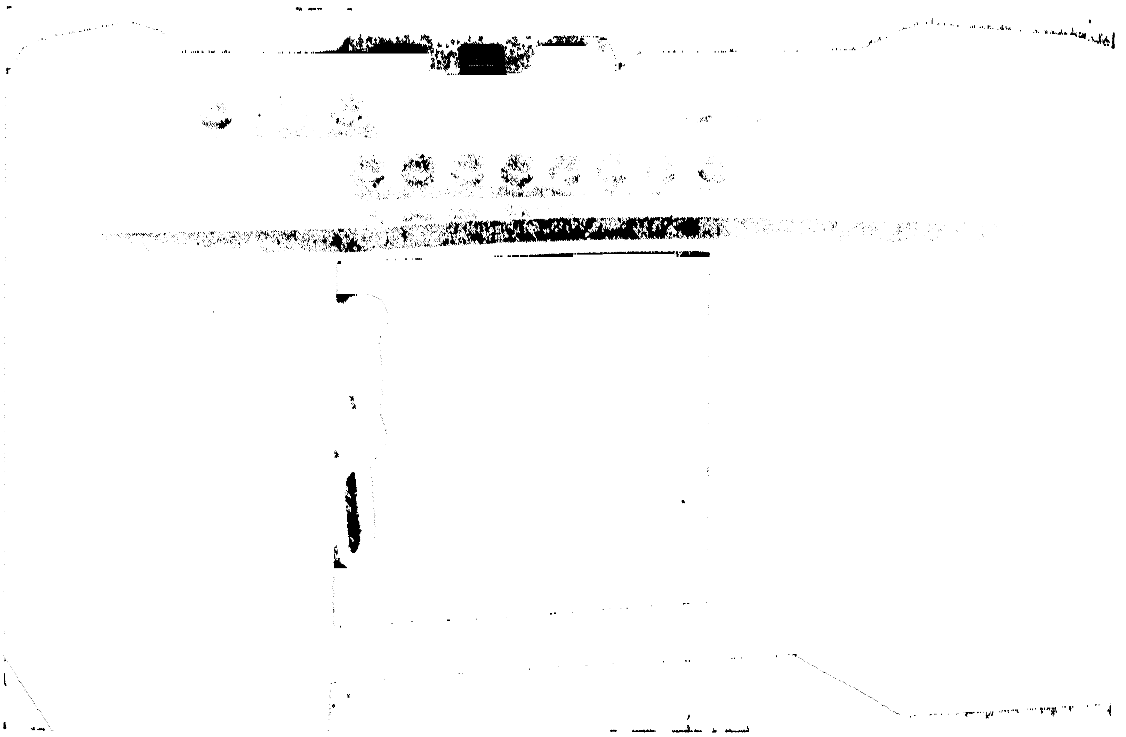

FIG. 9–73. A front view of the CBS 3B studio controle console. Microphone mixer positions 1 to 7 and the channel 1 master volume control are arranged across the lower portion of the center section.

The A and B position mixed controls, together with the associated incoming line push-button selectors and mixer key switches are located on the small panel in the center section immediately to the left of the script rack. The microphone mixer key switch is also located on this panel between the A position and B position key switches. The corresponding panel to the right of the script rack contains microphone mixer positions 8 and 9 and the channel 2 master volume control. Immediately above the two mixer controls are the reverberation push-button selectors which are used when these two positions are employed as reverberation mixer controls. The four key switches above the channel 2 master volume controls are two "utility" key switches, the "channel" key switch, and the "line" key switch.

The audio jack field and "sound-effects" filter occupy the entire panel space on the right wing of the console, while the left wing contains volume controls for the control room loudspeakers, studio loudspeakers, headphone-cue circuit, and rehearsal-break circuit. The "utility" volume control, rehearsal-break key switch, and telephone dial are also located on this panel.

Immediately below the table top are two telephone instruments. One is a regular dial extension while the other is a private line direct to the master program distributing center.

The over-all dimensions are 62 inches in length, 34 inches deep, and 39½ inches high. (Courtesy CBS.)

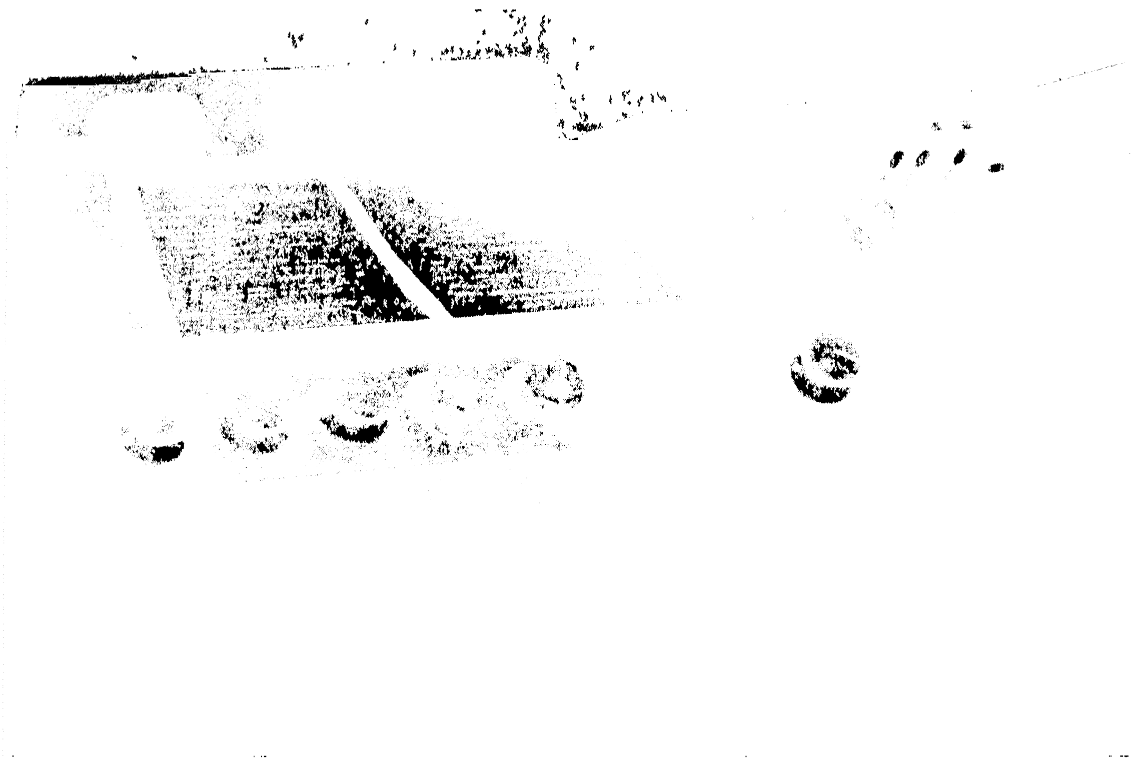

FIG. 9–74. A close-up of the center section of the mixer control panel of the CBS 3B console showing the control knobs which light when the mixer channel is in use. Two devices have been employed to eliminate marking the panels with pencilled notes and setting marks. The first are the small "magic slate" writing pads mounted above each mixer control. These permit the operator to make temporary markings which may be removed by lifting the clear plastic top sheet. The second device is a control knob setting indicator: a disc of clear plastic the same diameter as the skirt of the knob which is provided with a protruding indexing marker. This indicator is mounted between the control knob and panel and may be rotated until the indexing marker indicates the desired knob setting, established during rehearsals. The protruding indexing marker can be felt as the control knob is advanced, making it unnecessary to use the eyes in setting the control knobs to the desired point.

Immediately above the script rack is a panel containing the two volume indicators and the rehearsal-break microphone which is mounted behind the center grill work. This section has been made plug-in for the purpose of expediting maintenance.

At the side of each volume indicator are arrow-shaped red plastic indicators which light up to indicate the channel in use. These indicators are so interlocked with the "line," "channel" and "mixer" key switches that they light only when all switches are in the proper "on-air" position.

It will be noted that a black scale is employed on each of the volume indicators. The divisions and lettering on these black scales are made with paint containing a fluorescent material which glows under the influence of ultra-violet light. The meter pointer is coated with the same material. Small ultra-violet lamps are mounted directly beneath the volume indicators with the light entering the meter enclosure through an opening in the bottom of the meter case The fluorescent markings glow green on the scale range up to the reference point while the markings above the reference point glow in red. (Courtesy CBS.)

plugs and pairs of jacks, and the use of specially developed, small plug-in amplifier units. Two amplifier types, which require only two tube types, fill all amplifier requirements of this console. The plate and relay power supply units are also of the plug-in type and employ rectifiers of the selenium type, no rectifier tubes being necessary.

Other features of the 3B console include a program script rack, plastic control knobs that light up to form large, easily visible channel-in-use indicators, and pilot light panel indicators that change color as a function of key switch setting. Volume indicators equipped with a black scale containing fluorescent divisions and markings which are illuminated with black light are employed.

Visibility into the studio is not obstructed by control panels or script rack because of the physical design. The amplifier and power supply compartments were designed to provide adequate ventilation. The mechanical placement of components provides maximum separation between the power and audio units, thereby reducing hum pick-up to the lowest possible value.

A block diagram is given in Figure 9–76. It can be seen that an eleven-position mixer which permits the simultaneous mixing of nine studio microphones and two incoming program line channels is provided. Program material to these latter two channels, which are known as the A and B channel, may be selected from any one of five sources by means of push-button selectors.

Two complete and independent program channels have been included. The second channel, which includes separate visual and aural monitoring facilities, may be used as an emergency, test, or utility channel. Also included are rehearsal-break (talk-back) facilities, reverberation facilities, sound reinforcement feeds, headphone-cue circuits, and a sound effects filter. A utility volume control, utility key switches, utility bridging transformer and parallel-connected jacks are also included

A circuit impedance of 150 ohms, which has been employed throughout, assists greatly in achieving uniform response-frequency characteristics at the higher audio frequencies and, in addition, reduces cross-talk to an exceptionally low value

The performance characteristics of the CBS 3B console are well within the requirements dictated by good engineering practice and readily meet the F C C. requirements for A-M, F-M, and television sound broadcasting service. The response-frequency characteristics of the program channel are uniform, within 0.7 db of the 1000-cycle value, from 50 to beyond 15,000 cycles per second. The response-frequency characteristic of the monitoring channel (including the program channel) is substantially equivalent to that of the program channel.

The single-frequency harmonic distortion of the program channel, measured at an output level of + 20 dbm (which is 10 db greater than the normal program output level of + 10 *vu*), is less than 0.2 percent from 100 to 15,000 cycles, and less than 0.4 percent in the region from 50 to 100 cycles. The distortion through the monitor channel (including the program channel) measured at an output level of + 38 dbm, is less than 0.75 percent from 50 to

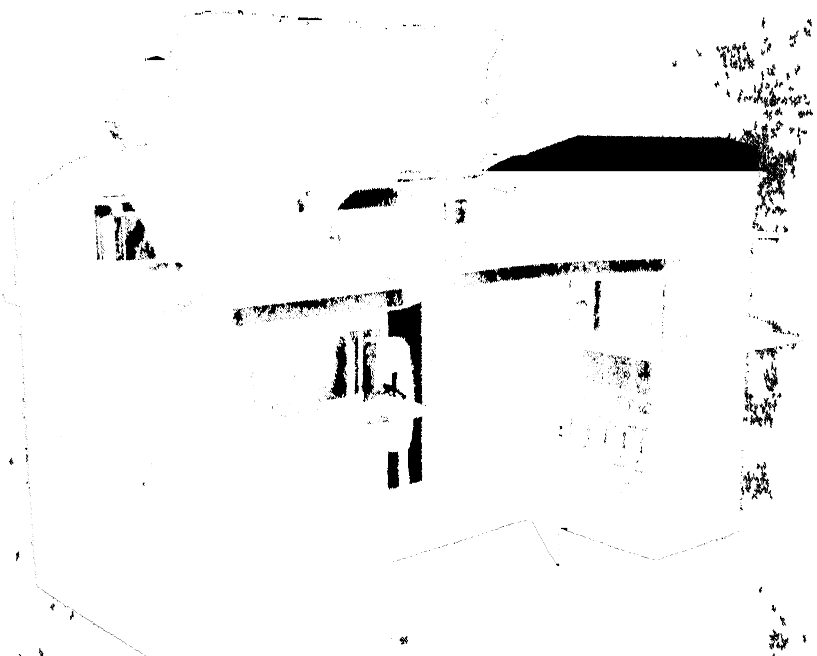

FIG. 9–75. A view of the CBS 3B studio control console with all access doors as well as the center control panel opened. This view shows how components may be reached for inspection and servicing.

The two pedestals of the console serve as equipment compartments. The forward section of the right-hand compartment contains all audio amplifier units as well as a compartment for storage of spare tubes, program scripts, pencils and other miscellaneous items. The rear section of this compartment contains the audio transformers, audio relays, audio terminal blocks, and resistance attenuation networks.

The power equipment is housed in the left-hand equipment compartment. The forward section of this unit contains two plug-in power supplies which provide amplifier plate power. The upper section contains a power panel, accessible through a small door in the front of the unit. A master on-off magnetic circuit-breaker switch, as well as regular-emergency, a.c. supply and regular-emergency low and high voltage supply transfer toggle switches, are mounted on this panel. The rear section of this compartment contains a 24-volt d.c. power supply for operation of relays and pilot lights, two filament lighting transformers, and "on-air" sign relays.

All power rectifiers are of the selenium type, no rectifier tubes being employed (Courtesy CBS.)

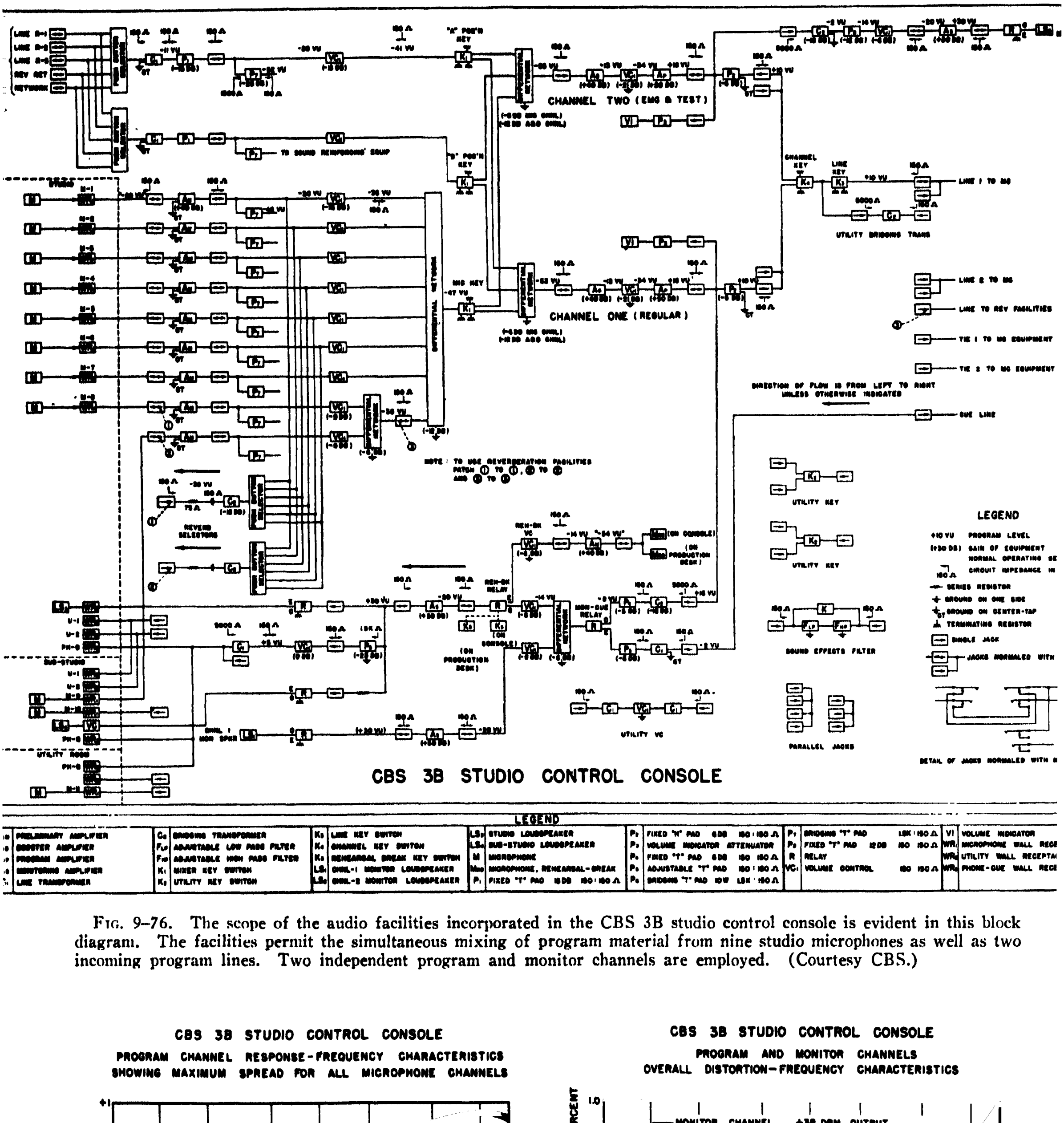

Fig. 9–76. The scope of the audio facilities incorporated in the CBS 3B studio control console is evident in this block diagram. The facilities permit the simultaneous mixing of program material from nine studio microphones as well as two incoming program lines. Two independent program and monitor channels are employed. (Courtesy CBS.)

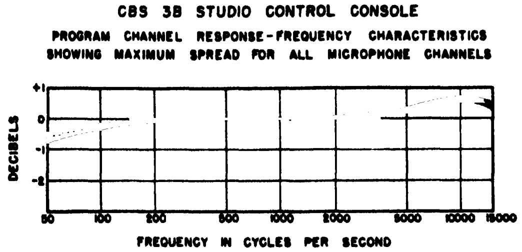

Fig. 9–77a. The curve above shows the response-frequency characteristics of the program channel of the CBS 3B console. From these data it may be seen that the performance is well within the requirements set forth for A-M, F-M, and television audio facilities. The signal-to-noise ratio of the complete program channel ranges from 73 to 75 db. (Courtesy CBS.)

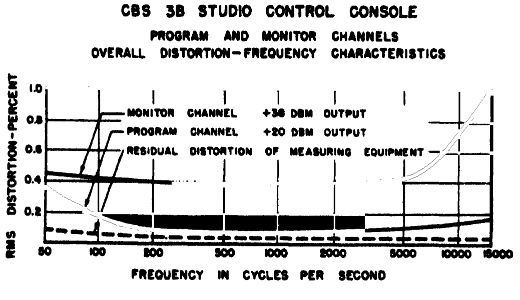

Fig. 9–77b. These curves show the distortion-frequency of the CBS 3B console. The program channel measurements were made at an output level of + 20 dbm which is 10 db higher than the normal program level. (Courtesy CBS.)

10,000 cycles, and less than 1.0 percent from 10,000 to 15,000 cycles. The signal-to-noise ratio of the various channels range from 73 to 75 db.

9-46. Western Electric 25-B Audio Console— Several basically new ideas in studio console design and operation have been built into the W. E. 25 type equipment. This console was designed by Bell Telephone Laboratories for use at broadcast stations using F-M transmission or at A-M stations planning to provide for F-M at some future time. Accordingly, high-fidelity service for F-M broadcasters is provided by the 25 type's uniform, noise-free, and low-distortion operation over a 15,000-cycle range.

The 25B equipment provides a seven-channel mixer circuit. The design is greatly simplified as to mounting and installation, requiring only a minimum of effort to put the two fully assembled and wired units into service.

The main unit houses two complete high-quality main amplifier channels, capable of simultaneous operation on different programs without interference or cross-talk. Also in this desk console are pre-amplifiers, mixers, switching, indicating, monitoring, cue feeding, and other control apparatus, arranged and co-ordinated to provide maximum operating flexibility and convenience.

A compact power supply unit serves the 25B equipment. This is arranged for wall mounting, and is generally located away from the console. The power supply unit, mounted on a swinging frame for easy inspection and maintenance access, contains the power supply units for plate and filament power to all vacuum tubes, and also for the loud-speaker cut-off relays. Thus the only need for any other auxiliary power supply is the usual d-c signal supply for operation of indicating lights and external relay systems where employed.

Built into the main housing of the console are eight microphone or low-level transcription input circuits and four pre-amplifiers, with switching keys for ready selection of either of two low-level inputs for each pre-amplifier. These are shown diagrammatically in the schematic circuit. Four of these circuits can be used simultaneously, with four in reserve available at a moment's notice, enabling the engineers to schedule programs of eight sources, or to dispatch two successive four-source programs. Three additional microphone or transcription sources can be introduced simultaneously through the three line mixers as explained below. Optional addition of jacks, lamps, or jack-sized keys for system control and indicating circuits give the 25B still greater utility.

Especially valuable to stations operating both A-M and F-M transmitters or simultaneously originating both local and network programs are the line facilities of this audio console. The two main

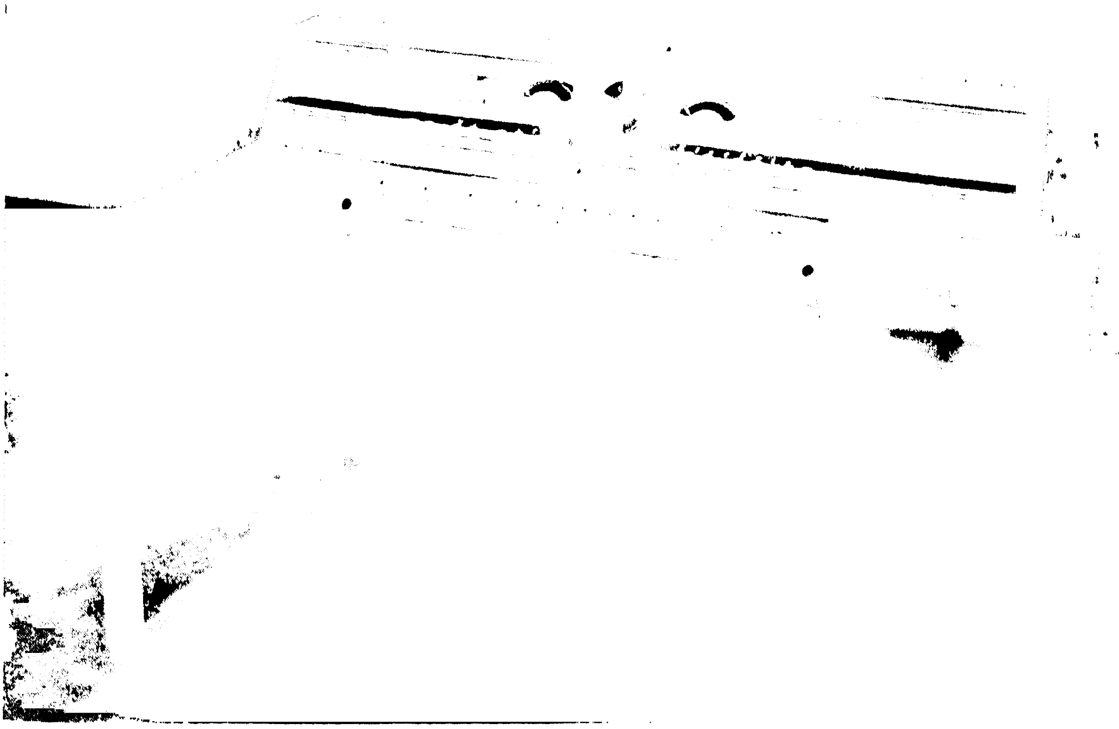

FIG. 9-78. Western Electric 25B console. (Courtesy Western Electric.)

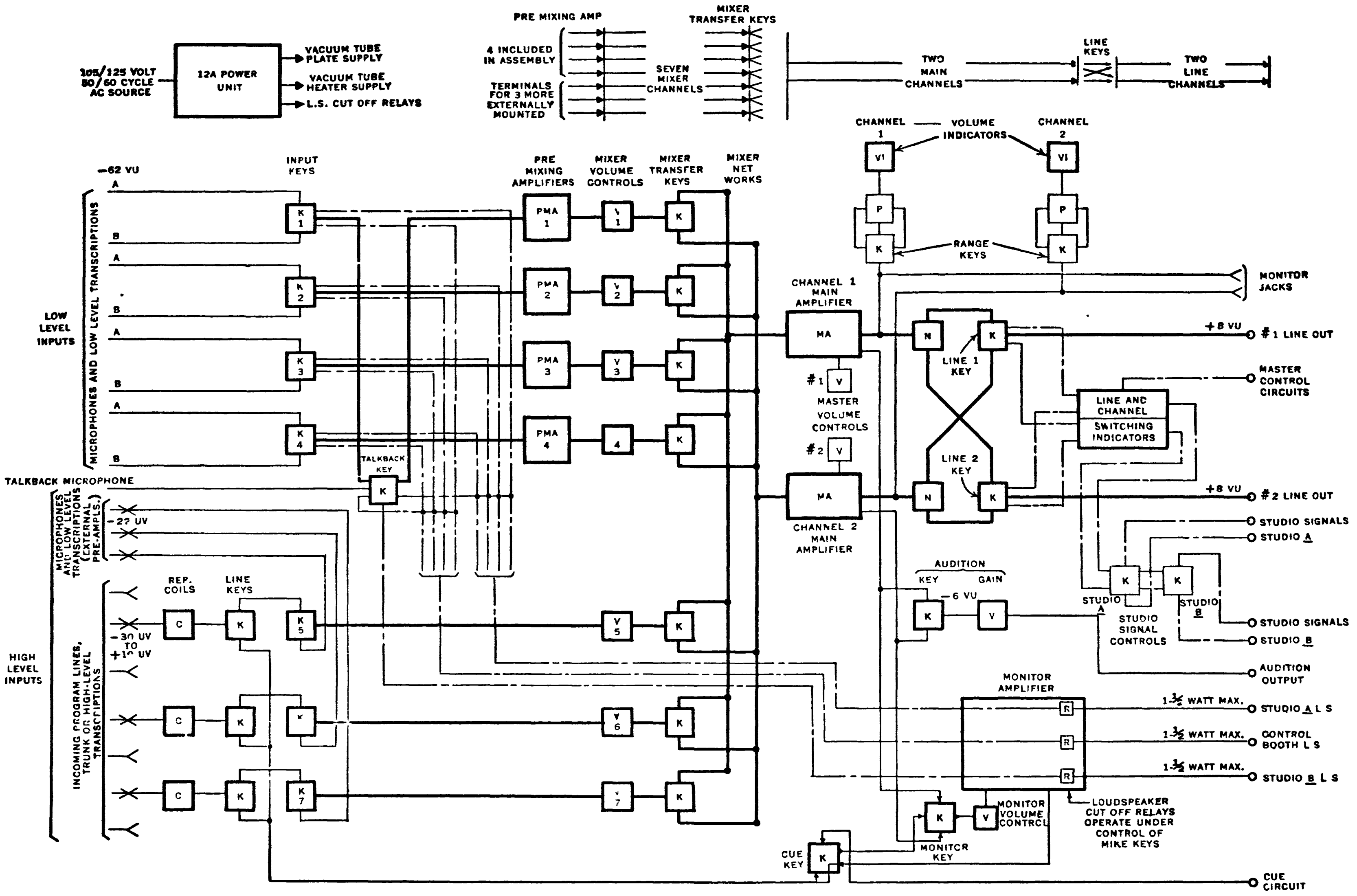

Fig. 9–79. Functional schematic for the Western Electric 25B audio control console.

amplifier channels, capable of simultaneous operation on separate programs, permit concurrent dispatch of audio signals to each of two transmitters or outgoing lines through the one console, each channel being governed by a separate master gain control for adjusting overall level. This set-up obtains flexibility through two line switching keys which allow either of the two main channels to be fed to either or both of two outgoing lines.

Three remote line input-circuits with repeating coils feed incoming line programs to three separate line mixer-controls. Ready and rapid selection of remote or network programs is speeded by three remote line switching keys, usable in selecting any one of three lines, for monitoring incoming programs, or for connecting to the associated mixer input. Patching jacks, with which four additional remote lines can be substituted on a line-for-line basis, make available a total of seven input lines or trunks.

Each of the line mixer inputs is provided with a transfer key switch which will allow an external utility circuit such as a transcription source or output of a microphone pre-amplifier to be switched in place of a line program source. Thus three additional microphone or transcription sources (a total of seven simultaneously) can be accommodated where required by providing externally mounted preamplifiers.

With seven mixer volume controls individual level adjustment on the three line or utility input circuits and on the four microphone input circuits, the 25B makes extensive provision for blending programs under a wide variety of operating situations. These volume controls operate on either of the two main amplifier channels through a seven-channel mixer circuit with individual mixer transfer keys for association with either main amplifier channel input.

Mounted on the console are two volume indicators for visual monitoring of program levels of the two main channels. In addition, headphone jacks for each channel are mounted on the housing for occasions when both channels are being used and monitored simultaneously, making headphone monitoring necessary on one of the channels. A built-in monitor amplifier which may be connected to either main channel is included for aural monitoring.

The monitor amplifier feeds cue programs into a studio speaker and the remote line circuits, while a monitor transfer key gives access to programs on either of the two main channels or to the cue transfer key. This key switches between the conditions of monitoring on the remote lines, receiving cue from master control, or feeding cue to remote lines. Operation of a loud-speaker in the same room with a live microphone is automatically prevented by loud-speaker cut-off relays for the booth and two studio loudspeakers. Contacts are also provided for operating equipment outside the system, such as studio warning signs, buzzer cut-offs, and other auxiliaries.

Other important features include an additional circuit with a gain control and a channel switching key to feed either main channel output to a separate amplifier system external to the console. This is invaluable for audition circuits, sound re-enforcement in large audience studios and similar applications. Normal operation of the amplifier tubes can be checked quickly by a plate-metering circuit with a meter and rotary tap switch for individual plate current measurement.

The dimensions of the console were held down to 36 inches over-all height and a width of 55¼

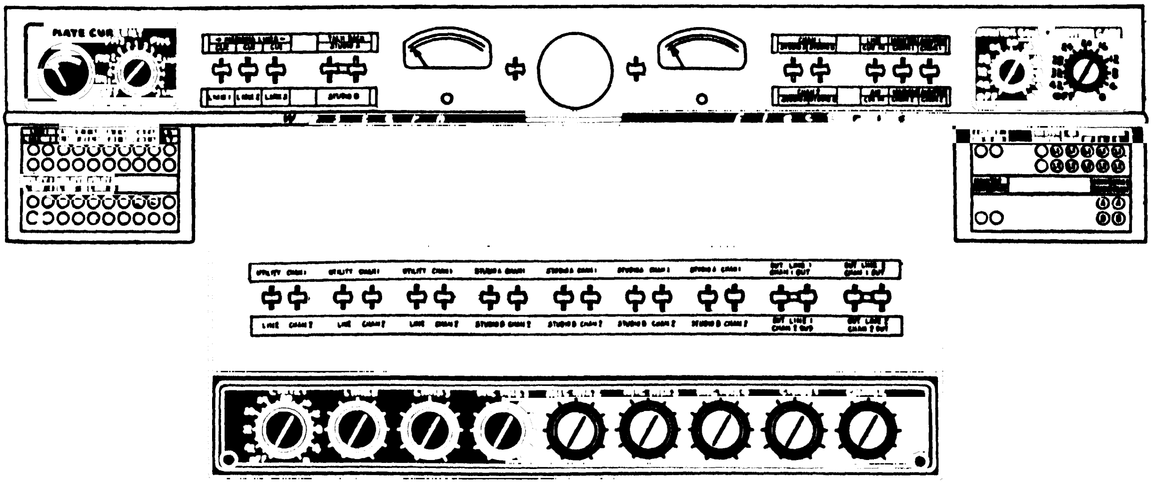

Fig. 9–80. Face panel layout of the Western Electric 25B Audio Console. The volume control knobs are of the mushroom type with wide skirts, raised pointers, and knurled to facilitate fingertip control. Flat type key handles of two colors with concave finger surface are used. The arrangement of the equipment permits good visibility to the studio All controls are functionally located.

inches. Over-all depth is 28¼ inches, of which the control cabinet at the rear is only 13½ inches. The table top stands 27½ inches from the floor. The power supply unit is 16½ inches high, 28 inches wide, and 10 inches deep.

A number of these consoles installed one to each studio control room or in a control room common to two studios will, with the help of master coordinating equipment, provide complete audio facilities for an entire station.

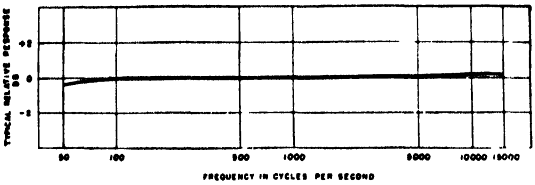

Fig. 9–81. Response-frequency characteristics of the Western Electric 25B audio console.

9–46a. Technical Data

1. *Frequency response:* See Figure 9–81.

2. *Signal-to-noise ratio:* 70 db unweighted, with 70-db net gain and with + 18-dbm peak signal for single frequency output level.

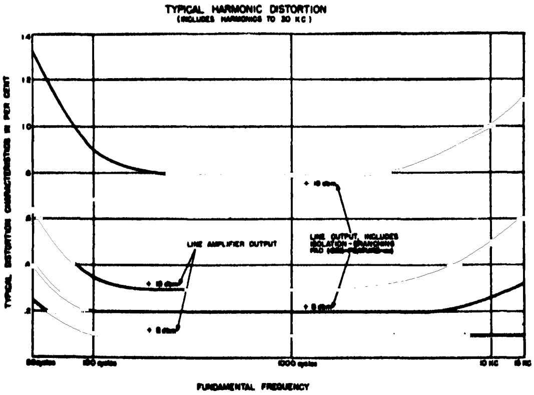

Fig. 9–82. Distortion-frequency characteristics of the Western Electric 25B audio console.

3. *Harmonic distortion:* See Figure 9–82.

4. *Source impedances*
   - Microphone inputs: 30–50, 250, or 600 ohms
   - Line inputs: 600 ohms
   - Utility inputs: 600 ohms
   - Air cue input: 600 ohms

5. *Load impedances*
   - Line outputs: 600 ohms
   - Audition output: 600 ohms
   - Monitor amplifier outputs: Furnished adjusted for loud-speaker impedances of 3 to 10 ohms. May be adjusted to a wide range of impedances, between 1 and 1200 ohms. Cue to line circuit is 600 ohms.

6. *Over-all gains*

	Max. Gain (db)	Typical Operating Gains (Approx.) (db)
Microphone inputs to line outputs.....	100	70
Remote line inputs to line outputs.....	38	24
Utility inputs to line outputs.........	58	30
Cue input to monitor output loud-speakers.........................	44	38
Cue input to remote line............	6	2

7. *Output power:* + 18 dbm. Allows 10-db margin for peak factor above + 8 *vu* which is normal program output for the equipment.

8. *Power source:* 105–125 volts, 50–60 cycles a-c, approximately 225 watts. Power for signal light and external relay operation must be supplied from external source.

9–47. RCA 76–B2 and 76–B4 Consolettes—The type 76–B2 and type 76–B4 consolettes have been designed for use in broadcast audio installations to provide a complete and flexible control system in one conveniently arranged unit. All the controls necessary for switching and mixing the audio outputs of microphones, transcription turntables and remote lines, as well as for auditioning and monitoring, are contained in a single cabinet. The consolette may be used as a complete control system for a small station, or to control a single studio in larger installations.

The consolette consists of a metal cabinet containing four pre-amplifiers, a program amplifier, an eight-watt monitoring amplifier, two line transformers and three loud-speaker relays. A VU meter, attenuator controls, switches, and other controls are mounted on a slanting front panel. An arrangement of switches makes it possible to use the VU meter to check the condition of the tubes in the program channel.

The 76–B2 and 76–B4 consolettes are similar in performance and operation and the instructions for installation and operation apply to both types unless otherwise specified.

The top of the consolette may be opened to inspect and service the tubes and relays, or the entire upper section, which is hinged at the back, may be lifted to expose the terminal boards and the bottoms of the mounting plates. Three terminal boards are provided for external connections. These are mounted on the bottom section of the chassis and are accessible when the upper section is lifted. The terminal boards are arranged so that the low-level audio terminals are separated from the high-level audio terminals and the power leads.

Five rubber-cushioned mounting plates are located on the hinged upper chassis as follows:

(a) Relay mounting plate, on which are mounted three relays and their associated equipment. Two terminal boards, on which connections are made to change over from two, or three,

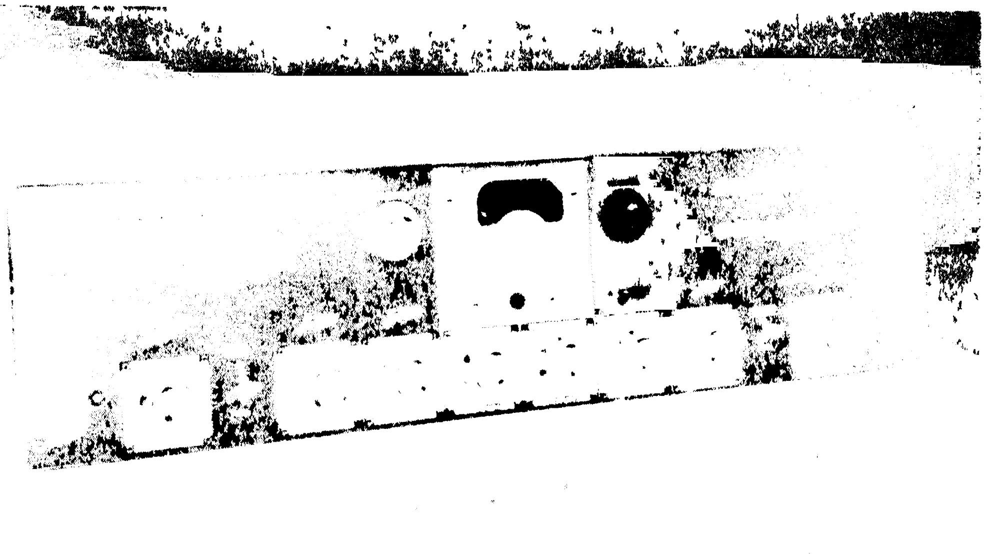

FIG. 9–83. The RCA 76 B consolette.

studio operation to single-studio operation are mounted under this plate.

(b) Monitor amplifier mounting plate, on which are mounted the components of the monitor amplifier and the monitor amplifier booster stage

(c) Line transformer mounting plate, on which are mounted the two line transformers and associated resistors

(d) Preamplifier mounting plate, on which are mounted the four preamplifiers.

(e) Program amplifier mounting plate, on which are mounted the components of the program amplifier and the program amplifier booster stage.

9–47a. Technical Data

1. *Gain*
   - Microphone input to line output: 112 ± 2 db.
   - Transcription input to line output: 81 ± 1½ db.
   - Line input to line output: 54 ± 1½ db.
   - Microphone input to monitor output: 110 ± 2 db.
   - Line input to monitor output: 54 ± 2 db.
   - Transcription input to monitor output: 80 ± 2 db
   - Cue input to monitor output: 34 ± 2 db.
   - Talk-back input to monitor output: 95 ± 2 db.
   - Line output to monitor output: 33 ± 2 db.
   - Microphone input to emergency line output: 91 ± 2 db.
   - Remote line through override: 27 ± 2½ db.
   - External record: 90 ± 2 db.
   - Remote talk-back: 77 ± 2 db.
2. *Line Output Level*
   - Normal: + 18 dbm with 0.5 percent rms harmonic distortion from 50 to 7500 cps.
   - Maximum: + 26 dbm with 1 percent rms harmonic distortion from 50 to 7500 cps.
3. *Tubes*
   - 11 RCA-1620 or 11 RCA-6J7 [11]
   - 2 RCA-1621 or 2 RCA-6F6 [11]
   - 2 RCA-1622 or 2 RCA-6L6 [11]
4. *Inputs*
   - Six 30- or 250-ohm microphone inputs (balanced)
   - Six line inputs, 150, 300, and 600 ohms (balanced)
   - Two 250-ohm transcription inputs (unbalanced).
   - One 250-ohm talk-back microphone input (balanced).
   - Five 20,000-ohm monitor cue lines (balanced).
5. *Outputs*
   - One 500 to 600 ohm line.
   - Three 15-ohm monitor lines.
   - One high-impedance headphone output (2000 to 5000 ohms)
6. *Line output noise level*
   - Microphone input at − 50 dbm to line output at + 18 dbm (68 db system gain): − 68 db.
   - Microphone input to monitor output at 4 watts (+ 36 dbm) output (86 db system gain): − 68 db.

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[11] May be used when maximum uniformity of characteristics, and minimum of microphonics, hum, and distortion are not required.

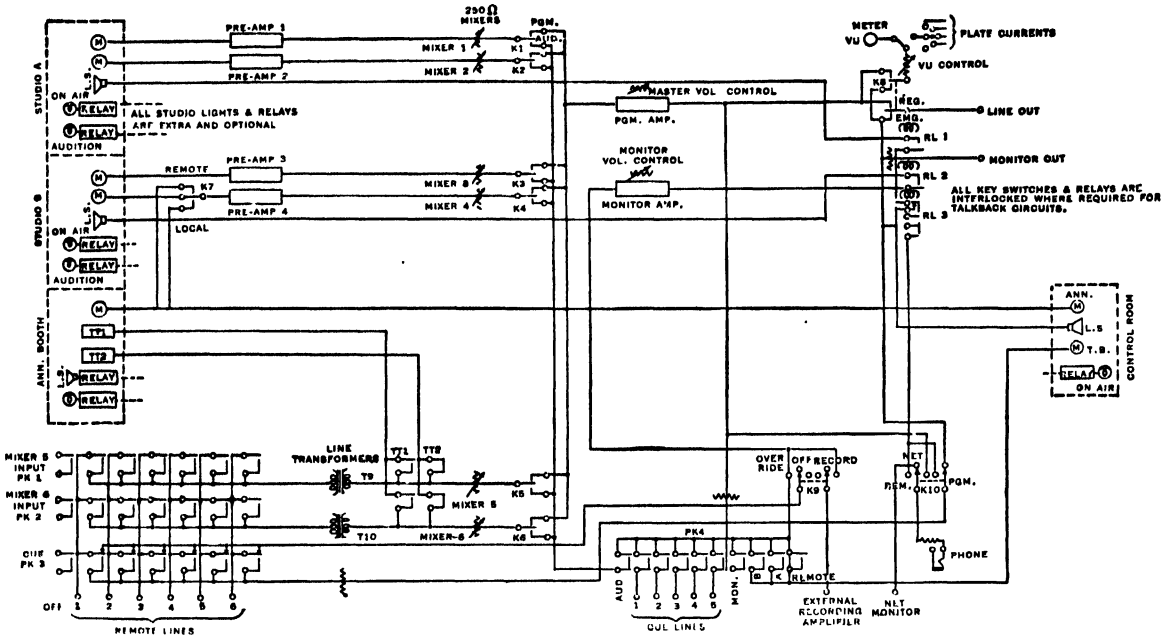


FIG. 9–84. Simplified schematic of the RCA 76-B4 consolettes.

7. *Distortion*

Microphone input to line output: 0.5 percent rms harmonic distortion from 50 to 7500 cps, with normal output of + 18 dbm.

Microphone input to monitor output: 1½ percent rms harmonic distortion from 50 to 7500 cps at 4 watts output.

8. *Frequency response*

Microphone input to line output: ± 2.0 db from 30 to 15,000 cps.

Microphone input to monitor output: ± 2 db from 30 to 15,000 cps (audition channel).

9. *Monitor power output*

4.0 watts (+ 36 dbm) with 1½ percent rms harmonic distortion from 50 to 7500 cps.

8.0 watts (+ 39 dbm) with 3 percent rms harmonic distortion from 50 to 7500 cps.

10. *Dimensions:* Width 39 inches, depth 17 inches, height 10½ inches, weight 135 pounds.

9–47b. Operation—An over-all block diagram of the consolette, showing controls and associated equipment, is shown in Figure 9–84. This diagram represents a typical installation in which the consolette is used in a small station to control two studios and a transcription booth from a single control room. The equipment can, of course, be used for single studio operation in larger stations.

All the controls are conveniently arranged on the front panel of the consolette. Figure 9–85 shows the front panel layout and arrangement of the controls.

Six mixer controls are arranged in a group at the center near the bottom of the panel. The first two of these are associated with the two microphones in studio "A," the third and fourth with the two microphones in studio "B," and the fifth and sixth with two sets of pushkeys which may be used to select any two of six remote lines or two transcription inputs.

Above the six mixer controls are six audition-program switches (K–1 to K–6) which control the input to the program and audition busses. The first four of these control the outputs of the first four mixers which in turn control the output of four microphone preamplifiers for the microphones in studios "A" and "B." A switch on the input of the fourth preamplifier may be used to switch to a fifth microphone in the control room for announcing, or a sixth remote microphone at some other point (such as a transcription booth).

Two sets of push buttons are mounted in the upper right-hand corner of the panel. These buttons are used in conjunction with the two line transformers to control the input to the last two mixer controls (K–5 and K–6). These transformers and resistor attenuating networks are arranged in such a way that the remote lines and transcription turntables are properly terminated and matched to the mixing pads. Each set of push buttons consists of nine buttons, interlocked so that only one can be used at a time. The push buttons numbered one to six in each group are connected respectively to six incoming remote lines, those

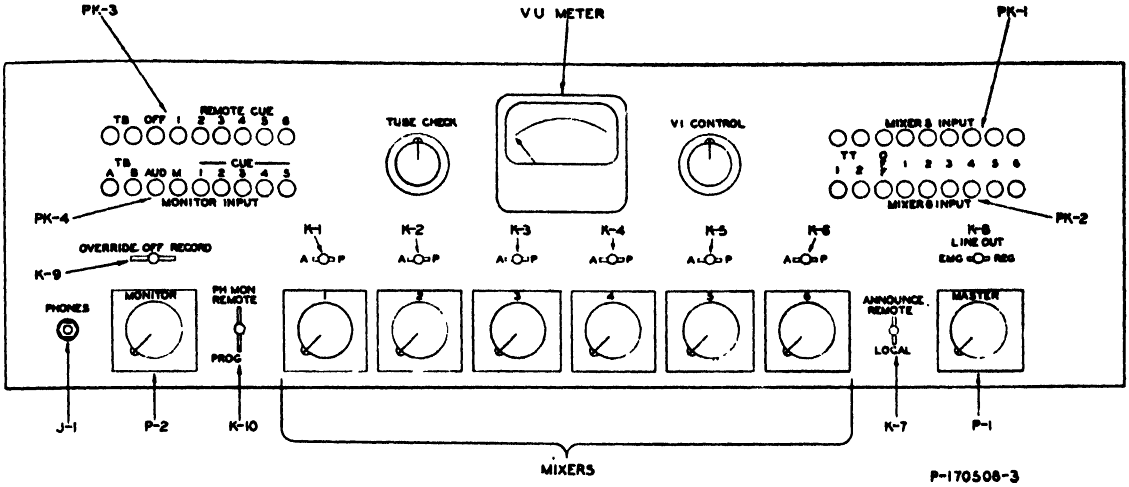


Fig. 9–85. Front panel layout of 76-B2 and 76-B4 consolettes.

numbered TT-1 and TT-2 to two turntables, and the remaining button is an OFF position.

The two sets of push buttons are electrically interlocked, making it impossible to place a single incoming remote signal or a single transcription turntable on both mixers at once. Number 5 mixer and associated push buttons have priority over number 6.

The outputs of the six mixers feed through a matching network into six PROGRAM-AUDITION switches. When these switches are in their normal positions, the outputs of the mixers are open while loading resistors are connected across both the program and audition busses.

When a PROGRAM-AUDITION switch is thrown to the PROGRAM position, the output of the corresponding mixer is placed on the program bus. When the switch is thrown to the AUDITION position, the signal is placed on the audition bus.

A detailed description of the various channels of the consolette is given below.

9–47c. Program Channel—The program bus is connected to the input of the program amplifier which consists of a booster amplifier and a three-stage program amplifier. The MASTER volume control is connected between the booster amplifier and the studio amplifier.

From the program amplifier, the signal passes to the LINE OUT switch which controls the output of the consolette to the out-going line. The LINE OUT switch has, in addition to its normal, or off, position, a regular and an emergency position (marked REG and EMG). When the switch is in the normal position, a load is connected across the program amplifier output. The volume indicator is connected across this circuit.

When the LINE OUT switch is in the REGULAR position, the output of the program amplifier is fed into the outgoing line with the load removed and the volume indicator still across the circuit. The function of the LINE OUT switch when in the EMERGENCY position is explained under *Emergency Program Channel* below.

When the PHONE-MONITOR switch is in the PROGRAM position, the program channel may be monitored by means of the phone jack and headphones.

9–47d. Audition Channel—The audition channel of the consolette is connected to one of a set of push buttons which determine the input to the monitor amplifier. These buttons, labeled MONITOR INPUT, are the lower of the two sets of push buttons in the upper left-hand corner of the front panel. The MONITOR INPUT push buttons permit the following functions to be performed.

1. *Monitoring.* One button (marked MON) connects the input of the monitor amplifier, through proper bridging resistors, across the output of the program amplifier. A program on the air may be monitored in this manner.

2. *Auditioning.* One button (AUD), as mentioned above, connects the output of the audition bus into the monitoring amplifier, making it possible to carry on an audition in one studio while the other studio is on the air.

3. *Cueing.* Five buttons, marked CUE and numbered from 1 to 5, are provided to select any one of five monitoring or cueing lines. These five buttons are mechanically interlocked with the monitor and audition buttons in such a way that only one can be on at a time. Any button, when pressed releases the button previously depressed.

4. *Talk-back.* Two buttons, marked TB and lettered A and B, are associated with the seven buttons mentioned above but not mechanically interlocked with them. These buttons are used for talk-back into studio A and studio B respectively Either button, when pressed, connects the talk-back microphone to the input of the monitor amplifier and turns the proper studio speaker on. Th

speaker interlock is more fully explained below. These buttons, although not mechanically interlocked with the other seven MONITOR INPUT buttons, are electrically interlocked so the talk-back microphone is connected to the input of the monitor amplifier when either button is pressed. The connection previously made is restored when the button is released.

9-47e. Remote Line Cue and Phone—The fourth set of interlocked push buttons (upper row in the upper right-hand corner of the front panel) are used as follows:

1. *Cue.* The buttons marked CUE and numbered 1 to 6 are connected to the six incoming remote lines. Pressing any of the buttons will connect the output of the monitor amplifier into the corresponding remote line provided the line is not already in use.

2. *Phone.* The phone jack makes it possible to listen to any of the remote lines by placing the PH. MON switch in the REMOTE position. It is possible to talk to any of the remote lines by pressing either of the two push buttons (marked TB) associated with the six remote cue buttons. When either of these buttons is pressed, the talk-back microphone is connected to the input of the monitoring amplifier and the output of the monitoring amplifier is connected into the remote lines. In this way a conversation can be carried on with any of the six remote lines by putting the PH. MON switch in the REMOTE position and holding down the remote line talk-back buttons. The two buttons are not mechanically interlocked with the six remote line cue buttons. A ninth button is used for an off position.

9-47f. Override Switch—When the switch marked OVERRIDE-OFF-RECORD is thrown to the OVERRIDE position, a signal on any of the six remote lines (not in use) will be heard in the monitor speaker.

9-47g. Emergency Program Channel—If for some reason, the program amplifier of the consolette should fail, the monitoring amplifier may be used in the program channel.

When the LINE OUT switch is thrown to the EMERGENCY position, the outgoing line is connected, through a bridging resistor, to the output of the monitoring amplifier. Thus, by placing the program signal on the audition bus and pressing the AUD button of the MONITOR INPUT the monitor amplifier will feed the outgoing line. The VU meter will also be transferred to the output of the monitor amplifier so that the level can be properly adjusted.

9-47h. Emergency "B" Supply—An emergency "B" supply for the four preamplifiers is also provided for the consolette. In case of failure of the B + power, which is normally obtained from the program amplifier rectifier, a switch on the MI-11301-B power supply can be thrown to obtain B + power for the preamplifiers from the monitoring amplifier rectifier.

9-47i. Relay Operation—An interlocking relay system is used in the consolette to provide the necessary function of controlling the output of the monitoring amplifier to the three speakers, and the supplementary function of controlling the signal light equipment. The speaker relays are a part of the consolette, while signal-light relays, although not furnished, can easily be connected. The consolette contains three speaker relays, one each for the control room speaker, studio A speaker and studio B speaker. The three relays are controlled by the following switches:

(a) ANNOUNCE switch.

(b) Four Program-Audition switches.

(c) LINE OUT switch.

(d) Talk-back buttons of the MONITOR INPUT group.

(e) Remote talk-back button of remote line push buttons.

Although the control room speaker is normally on, the control room speaker relay is normally unenergized. If the speaker relay power should fail for any reason, the control room speaker will remain on. The two studio speaker relays are energized when the speakers are on and unenergized when the speakers are off, so that the studio speakers will remain off if the power supply should fail.

9-47j. Suggested Operating Procedure

1. *To Place a Program on the Air.* The following procedure may be used to place a program on the air. (Assume that microphone 1 in studio A is to be used.)

a. With all switches in their normal (off) positions, press the proper CUE or MONITOR push button and regulate the MONITOR volume control to obtain the desired volume level from the studio and control room speakers.

b. Throw the microphone switch A-P 1 to the "P" position.

c. Adjust the MASTER attenuator to approximately step 13.

d. Adjust mixer number 1 to determine the proper level setting as indicated by the VU meter. This setting should be approximately step 13 when a signal of normal intensity is being picked up by the microphone. Next return mixer number 1 to "0."

e. Throw the LINE OUT switch to the REG position at the moment the microphone is to go on the air. (The cue signal is removed from the studio speaker when this switch is thrown.) Then adjust the mixer control to the previously determined setting.

f. Press the monitor push button and adjust the monitor volume control as may be necessary.

If any other input is to be used, the above procedure should be followed except that switches and mixers should be operated as follows:

Input	Switch	Mixer
Mic. 1, studio A	Mic. A-P no. 1 to P	1
Mic. 2, studio A	Mic. A-P no. 2 to P	2
Mic. 1, studio B	Mic. A-P no. 3 to P	3
Mic. 2, studio B	Mic. A-P no. 4 to P and ANN sw. to norm.	4
Remote lines	Mic. A-P no. 5 or 6 to P and, corresponding input P-K 1 or P-K 2	5 or 6
Transcription Turntable no. 1	A-P 5 or A-P 6 to P, and TT-1	5 or 6
Transcription Turntable no. 2	A-P 5 or A-P 6 to P, and TT-2	5 or 6

2. *To Audition Studio B while Studio A is on the Air.* To audition studio B while studio A is on the air, proceed as follows:

a. With the talk-back and monitor push buttons in the normal (off) positions, press the AUD push button and throw the microphone switch, A–P number 3, to the A position.

b. Adjust mixer number 3 and the monitor volume control to obtain a suitable output from the control room loudspeaker.

3. *To Cue Studio B from Studio A and then Place Studio B on the Air.* Assuming that microphone number 1 in studio A is in use and it is desired to place microphone number 1 in studio B on the air, it is necessary to perform only the following steps at the moment studio B is to go on the air (since studio B loud-speaker is already receiving the signal from studio A).

a. Close mixer number 1.

b. Throw microphone switch A–P number 3 to the P position.

c. Adjust mixer number 3 to the proper level as indicated by the VU meter.

4. *To Cue Studio B from a Cue Line and then Place Studio B on the Air.* Assuming that microphone number 1 is in use in studio A and that studio A is on the air, proceed as follows:

a. Press the proper CUE line push button and regulate the monitor volume control to obtain the desired volume from studio B speaker. The cue line may be monitored by the control room speaker.

b. At the moment studio B is to go on the air, perform the following operations in quick succession:

(1) Close mixer number 1.

(2) Throw microphone switch A–P number 3 to the P position. (Assuming microphone number 1 in studio B is to go on the air.)

(3) Adjust mixer number 3 to the proper level as indicated by the VU meter.

5. *To Talk Back to Studio A or Studio B.* To talk back to either studio A or studio B proceed as follows:

Press the talk-back push button A or B according to the studio desired, and talk into the talk-back microphone. This cannot be done when either studio is on the air since the LINE OUT switch interlocks electrically to prevent the studio speaker relay from coming on.

6. *Announcing.* When using the 76–B2 consolette, the announce booth "On Air" lamp will light when K–7 is thrown to the REMOTE position. For this reason, when the announcement is to be made from the remote microphone, it is advisable to first throw K–4 to the PROG position and then operate the ANNOUNCE switch at the instant the announce booth microphone is to go on the air.

Because of additional contacts on K–4 in the 76–B4 consolette, the ANNOUNCE switch K–7 may be thrown to REMOTE and then K–4 to PROG when ready for the announcement, since the announce booth "On Air" lamp will remain off until K–4 is closed.

Note: When using microphone number 4 (see Figure 9–97) in studio B, it is possible to throw the ANNOUNCE switch (K–7) and allow studio B to hear the announcement and then be returned to the air.

7. *Emergency Use of Monitor Amplifier.* In case of failure of the program amplifier during a broadcast, the monitor amplifier may be used pending repair of the program amplifier in the following manner: Assuming that microphone number 1 is on the air when the trouble occurs, quickly throw A–P switch number 1 to the A position, press the AUD push button, and throw the LINE OUT switch to the EMG position.

8. *Network Monitoring.* When the proper terminals are connected to the network, or other outside signal; the operator may listen to the signal, by using the headphones, when the PHONE MONITOR switch is in the normal (middle) position.

9–47k. Power Supply—The MI–11301–B power supply furnishes plate, heater and relay requirements for the RCA 76–B series of consolettes. It also supplies loud-speaker field power for a maximum of three 100-volt, 10-watt loud-speaker fields.

The cabinet is provided with ventilating screens at the top and bottom. The conduits which carry the wiring to the unit are brought into the power supply through knockout holes in the sides of the cabinet. External connections are made to a terminal board at the left of the chassis. Tubes, terminal connections, fuses, resistors and wiring are accessible when the hinged door is opened to the right. Other resistors, condensers and transformers are mounted on the back of a hinged chassis which may be swung outward for testing and servicing. A safety switch is provided which removes the power from the circuit when the door is opened. A POWER ON-OFF toggle switch is mounted on the side of the cabinet. The MI–11301–B power supply is designed for wall mounting and is provided with suitable mounting brackets. The power supply should be mounted near the consolette to reduce

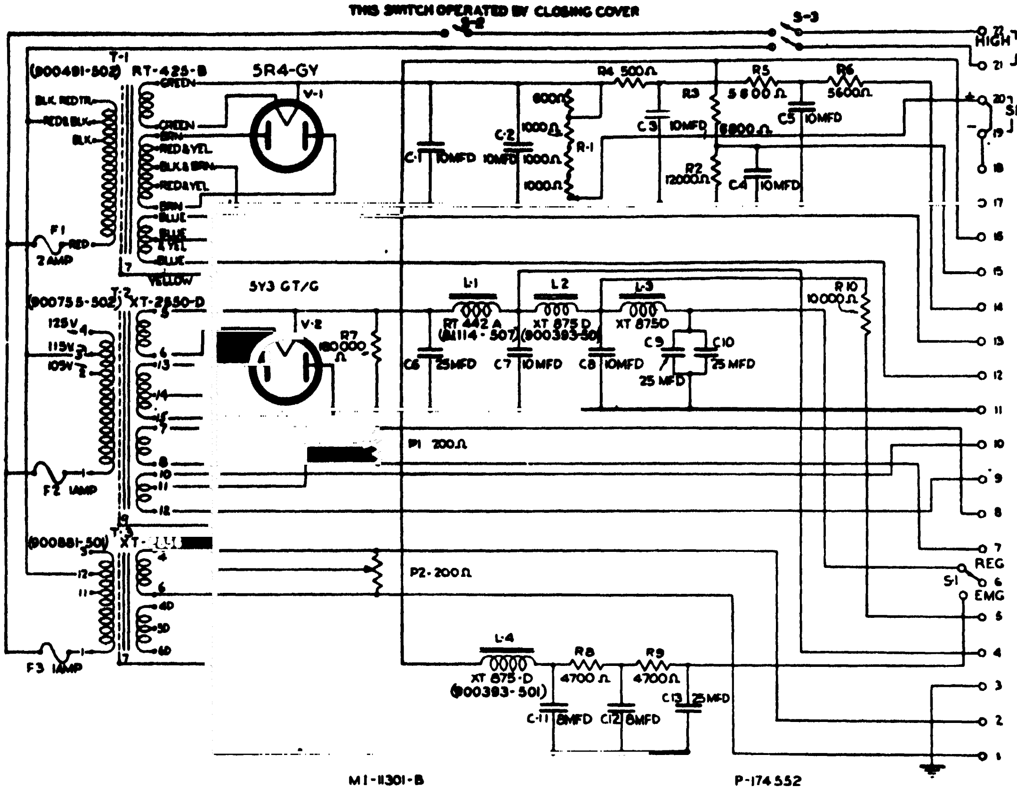


Fig. 9–86. Schematic diagram of the RCA MI-11301-B power supply.

wiring, but not closer than 3 feet to avoid hum induction.

9–471. Inspection and Checking—Particular attention has been paid in the design of the 76–B2 and 76–B4 consolettes to provide the best facilities for reaching and servicing the component parts. The lid of the consolette is hinged so that the tubes are accessible for inspection and servicing. It may be opened by turning the two spring catches through 90° with a thin coin or small screwdriver. The upper section of the cabinet may also be raised to expose the terminal boards and other components.

For any piece of equipment that is subject to continuous use, as is most broadcast equipment, a regular routine of inspection should be set up and followed to avoid time off the air as a result of tube failure, or noisy circuits caused by accumulation of dirt on terminals and switches, corroded plugs, etc. It is advisable to carry one complete set of spare tubes in case of emergency.

The regular inspection should include checking the tubes. To check the tubes, first turn the VU CONTROL to the OFF position. The bias voltage of all tubes in the program channel may then be checked by turning the TUBE CHECK switch to its various positions and observing the VU meter readings. The bias voltage provides an indication of the flow of plate current, thereby giving an indication of the condition of the tubes. The normal meter readings for the tubes are listed below.

Selector Switch Setting	Tube	Meter Reading	Selector Switch Setting	Tube	Meter Reading
1	RCA-1620, preamplifier number 1	70 ± 10	6	RCA-1620, 1st stage of monitor amplifier	70 ± 10
2	RCA-1620, preamplifier number 2	70 ± 10	7	RCA-1620, 2nd stage of program amplifier	70 ± 10
3	RCA-1620, preamplifier number 3	70 ± 10	8	RCA-1620, 3rd stage of program amplifier	70 ± 10
4	RCA-1620, preamplifier number 4	70 ± 10	9	RCA-1621, output stage of program amplifier	70 ± 10
5	RCA-1620, 1st stage of program amplifier	70 ± 10	10	RCA-1621, output stage of program amplifier	70 ± 10

These readings were taken with an a-c line voltage of 115 volts, the power transformers of the power supply being connected for 115-volt operation.

The tube socket and tube cap contacts should be cleaned with carbon tetrachloride or crocus cloth every three months to insure noiseless operation.

The mixer and master control switch contacts should be cleaned by applying Davenoil to the contacts, rotating the knob, and, if any dark streaks appear, wiping off the contacts. Repeat this procedure until absolutely clean, then lubricate with a thin film of Davenoil. No other cleaning agent, such as carbon tetrachloride, should be used.

Push button switches of the 76–B2 consolette should be cleaned every four to six months, or more often if dust and climatic conditions make it necessary. They should be cleaned using the push button cleaning kit supplied with the consolette.

Push button switches of the 76–B4 consolette are of a different type than those used on the 76–B2. They should not require cleaning under normal circumstances, but if noise is encountered as a result of dirty push button contacts, they may be cleaned from the rear of the panel as follows:

(a) Remove the two screws at the extremes of the push buttons and pull the switch assemblies back from the panel without removing any of the connecting wires.

(b) Using a toothpick or similar object apply a drop of Davenoil through each of the small eyelet holes directly over the switch contacts.

(c) Work the plungers in and out and remove the excess oil from the switch assemblies.

(d) Replace the switch assemblies.

The various key switch contacts have been adjusted to give the proper sequence of circuit connections as they are operated so that a microphone and speaker will not be on at the same time in a studio and thus cause acoustic feedback. In case a replacement key switch is installed, or if feedback trouble is encountered, the contacts should be adjusted using a standard key-switch or relay-contact bending tool. When adjusting the switches, the following desired sequence of operation should be kept in mind: *The relay contacts must operate first and the audio circuits transfer last.* This is accomplished by relieving the tension of the center spring of the form D contacts controlling the relays, and increasing the tension of the center spring of the form D contacts carrying audio. Care should be taken that the spring shape is not altered, or the contact pressure reduced so much as to cause poor contact or short circuits. To remove the key switch shield, it is only necessary to remove the two screws, in the contact "pile-ups" of the switches at the ends of the switches.

Tube voltages for the preamplifiers, program amplifier, and monitor amplifier are listed below. To obtain the values listed, all except heater voltages should be measured to ground, using a d-c voltmeter with a meter resistance of 5000 ohms per volt. Voltages listed are nominal and actual readings should not vary more than about 5 percent from the given values. If the voltmeter used has a meter resistance greater, or less than 5000 ohms per volt, most readings taken will vary accordingly, the amount of variation depending upon the circuit in which the meter is used.

Tube Voltage Table

PREAMPLIFIER VOLTAGES

Tube Element	RCA-1620
Plate d-c	220
Cathode d-c	8.3
Heater a-c	6.2

PROGRAM AMPLIFIER VOLTAGES

Tube Element	1st RCA-1620	2nd RCA-1620	3rd RCA-1620	Each RCA-1621
Plate d-c	155	80	85	270
Screen d-c	....	70	....	....
Cathode d-c	6.0	1.9	2.2	23
Heater a-c	6.2	6.2	6.2	6.2

MONITOR AMPLIFIER VOLTAGES

Tube Element	1st RCA-1620	2nd RCA-1620	Each RCA-1620 Phase Inverter	Each RCA-1622
Plate d-c	155	115	140	340
Screen d-c	....	....	....	220
Cathode d-c	5.8	4.3	5.0	12
Heater a-c	6.2	6.2	6.2	6.2

9–48. Master Control Facilities—A large broadcast plant, such as a network key station, which employs a large number of studio units, and often transmits many different programs simultaneously to a network of stations throughout the country, must be equipped with suitable switching facilities capable of performing all the required program routing operations. Such a central switching and program distribution system is known as a "Master-Control."

Fundamentally, the function of the master-control facilities is to distribute properly program material from any of the many points of program origination to the various outgoing program lines. In addition, it is common practice to centralize many other technical activities in the master-control room, such as private-line telephone switchboard operation, operation of monitor loud-speakers located throughout the building, and plant testing and measuring operations. The master-control room also usually serves as a central equipment room, where all equipment, other than that in the individual studio control rooms, is located.

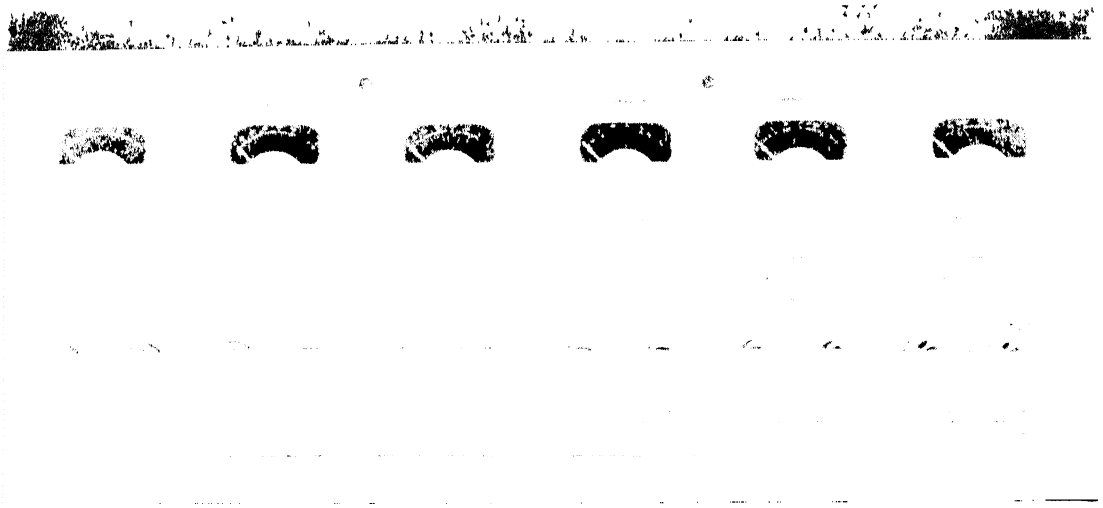


FIG. 9–87. The switching section of the master control facilities at WFAA-KGKO. Provisions are made for switching ten studios, or other program sources, to six outgoing program lines. Each of the volume indicators is permanently associated with an outgoing line and the selection of the program source is made by means of the rotary selector switch below, and to the left of, the volume indicator. When a studio is pre-set, this is indicated on the lower row of green signal lights. When the studio is switched on the air, this is indicated on the upper row of red signal lights. Any of the six sections may be switched on the air individually by throwing the appropriate key switch to the "operate" position, or, if desired, all sections may be operated simultaneously by setting the key switches to the "master" position and then, at the proper time, operating the master key switch which is located in the center of the panel. After the pre-set studios have been switched on the air, the rotary switch is free to select the following program source. The volume level to any line can be adjusted by means of the volume control to the right of the rotary selector switch. (Courtesy RCA.)

Although many different master-control selector and switching arrangements have been devised, depending usually on the scope of the switching operations, the basic principle of operation of these systems is always the same. The program lines from all the studios, as well as other points of program origination, are terminated in the master-control room. There, the desired studio or other program line is picked up by means of a suitable selector system and connected to the desired outgoing program lines which feed the various legs of the network. The switching system is usually so designed that the program distribution may be set-up some time prior to actual air-time. This is known as "pre-setting." At the proper time, the operation of a master switch energizes the necessary relays to interconnect the desired studios and outgoing program lines. The following program distribution may then be pre-set, to be placed on the air at the proper time. Inasmuch as pre-setting is essential for smooth and accurate operation, the actual switching is almost always accomplished by means of relays.

The complexity of a master-control switching system will be determined by the number of studios or other points of program origination to be selected, the number of outgoing lines to which the programs are to be transmitted, the number of different programs to be transmitted simultaneously, and the basic complexity of the type of switching system employed. Two different switching arrangements are shown in Figures 9–87 and 9–88.

A simplified block diagram of a typical master-control installation, omitting all but the essential circuit elements, is shown in Figure 9–89. In this illustration, program lines from seven studios, and incoming program lines from ten remote points are the sources of program material. Two remote channels, designated Remote Channel 1 and Remote Channel 2, into which the program line from the desired remote point may be patched, are provided. These remote channels contain the necessary line terminal equipment, including line equalizers, as well as a program amplifier to step-up the low incoming line level to the standard level being received from the studios. Both studio and remote channels are terminated in resistor loads before entering the selector and switching facilities.

Five outgoing program channels feeding five different outgoing program-lines are shown. Each channel contains a bridging amplifier, line pad, line coil, as well as a volume indicator for visual monitoring, and a monitoring amplifier and loud-speaker for aural monitoring of the program material.

9–49. Bridging Amplifier—A bridging amplifier, such as those shown in the outgoing program lines of Figure 9–89, has a very high input impedance, usually 20 to 100 times the impedance of the circuit being bridged. The bridging amplifier is intended to be connected across a terminated program circuit without causing any appreciable change in the impedance relations or volume level in the program circuit.

The bridging amplifier in each outgoing line channel serves two important functions. First, it permits any reasonable number of outgoing channels to be connected across any one studio bus. As an example, should a program from one studio be transmitted to all outgoing lines, all the bridging amplifiers would be connected across the one studio bus. Provided the input impedance of the amplifiers is high enough, the combined loading of all amplifiers will have no appreciable effect on the impedance relations or program level in the studio bus. The second important function of the bridging amplifier is to provide isolation between the various outgoing program lines. Should two or more program lines carrying the same program be connected together, as would be the case if the bridging amplifier were not employed, any noise, short-circuit, ground or other fault developing on one line would affect the other lines. The bridging amplifier, being a one-way device, completely isolates all program lines and eliminates this undesirable possibility.

Bridging amplifiers used in broadcast work usually have an input impedance ranging from 20,000 to 30,000 ohms, and an output impedance of 150 and 600 ohms. An insertion gain of 6 db is usually adequate, that is, if the amplifier is bridged across a program bus carrying a volume level of +8 vu, the output of the bridging amplifier will be +14 vu. This will result in a level of +8 vu on the outgoing program line after the program has passed through the customary 6-db line pad. In accordance with the principles of good amplifier design

FIG. 9–88. The master control switching system at KNX in Hollywood provides facilities for switching program material from eighteen studios, or other points, to six outgoing programs lines. Studios are selected by means of the rotary selector switches at the lower portion of each of the six switching sections, each section being permanently associated with an outgoing program line. The number of a studio that is pre-set appears in lighted green numerals on the upper translucent indicating screen. When the studio is switched on the air, the numerals appear in red on the lower screen. Operation of the switching sections may be accomplished individually by means of switches on the individual panels, or, if desired, they may be operated as a group by means of a "master" switch. When a studio has been switched on the air, the studio selector switch is free to pre-set the following program. Outgoing volume level is indicated by the volume indicator on each panel and may be adjusted by means of the control immediately above the volume indicator. (Courtesy CBS.)

already outlined, the bridging amplifier should be capable of an output level of at least +24 dbm (about 250 milliwatts) without excessive distortion.

9–50. Langevin Type 118–A Bridging Amplifier—The type 118–A amplifier is a small, fixed-gain, plug-in, single-stage, push-pull bridging amplifier designed to bridge terminated 600-ohm program lines. This amplifier provides an insertion gain of 6 db, having just sufficient gain to overcome the loss of the bridging input connection. and the loss of an external 6-db line pad. The 118–A amplifier provides an isolation of 75 db or more between its output and the program circuit being bridged. Two 6AK6 vacuum tubes in a push-pull circuit are employed in this amplifier as shown in Figure 9–90.

9–50a. Technical Data

1. *Insertion gain:* 6 db (from bridging input to line pad input).
2. *Input source impedance:* 600-ohm terminated program line.
3. *Output load impedance:* 600 or 150 ohms.
4. *Isolation:* 75 db at 15 kc, 90 db at 50 cps.
5. *Output power:* + 24 dbm (0.25 watt) with less than 1 percent total rms harmonic distortion at frequencies between 100 and 15,000 cps and less than 1.5 percent total harmonic distortion at 50 cps.
6. *Output noise:* 99 db below +24 dbm (75 db below .001 watt).
7. *Frequency characteristics:* ± 1.0 db over the range 50 to 15,000 cps.
8. *External power requirements:* 6.3 volts at 0.3 amp. Plate 225 volts at 35 ma.
9. *Dimensions:* Height $6\frac{11}{16}$ inches, width $6\frac{1}{8}$ inches, depth $4\frac{1}{8}$ inches, weight $2\frac{1}{2}$ pounds.

9–50b. Connections

Plug Pin Nos.	Circuit	
1, 2	25,000 ohm bridging input	
3	Plus VT-1	Metering circuit
4	Minus VT-1	
5	Minus VT-2	
6	Plus VT-2	
7	B+ 225 volts d.c. at 35 ma	
8	B−	
9	Spare	
10, 13	600 or 150 ohms output	
11, 14	Filament 6.3 volts at 0.3 amp	
12	Chassis ground	

9–50c. Metering Circuits—Metering circuits are designed for a percentage type meter with a 200-microampere movement. A series resistor should be added of such value that the total resistance of meter and resistor is 1000 ohms. One hundred percent on the meter will be at 75 percent of full scale.

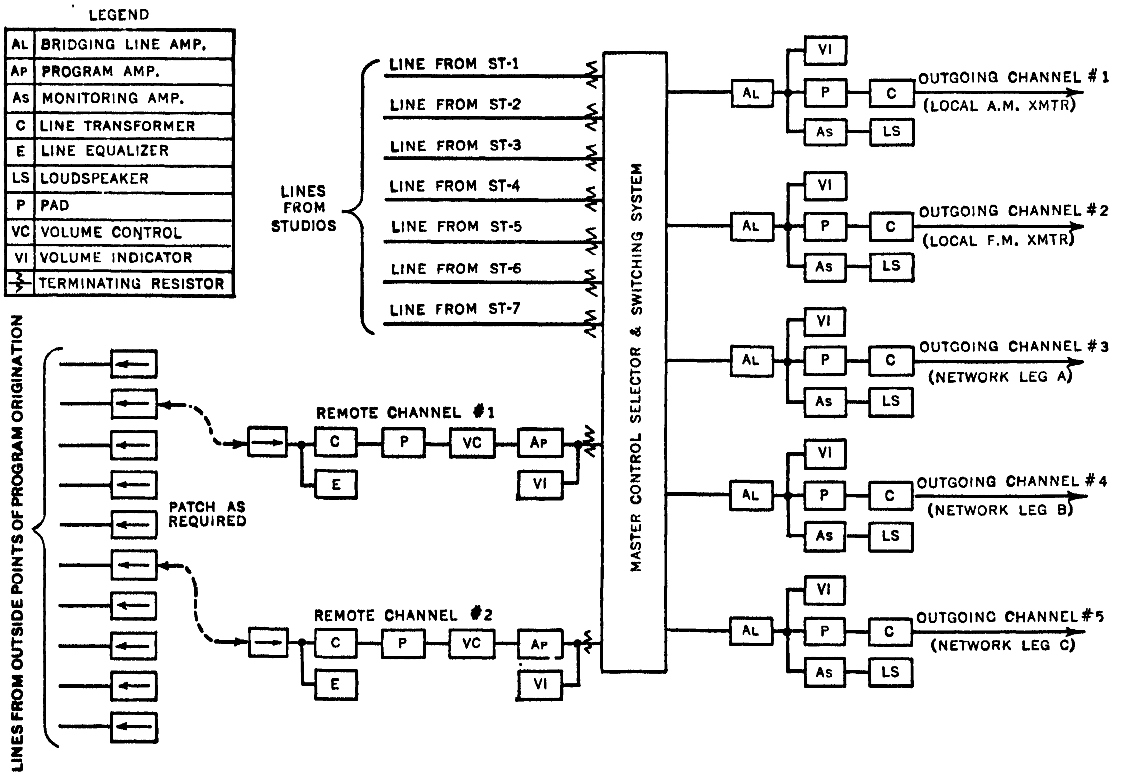
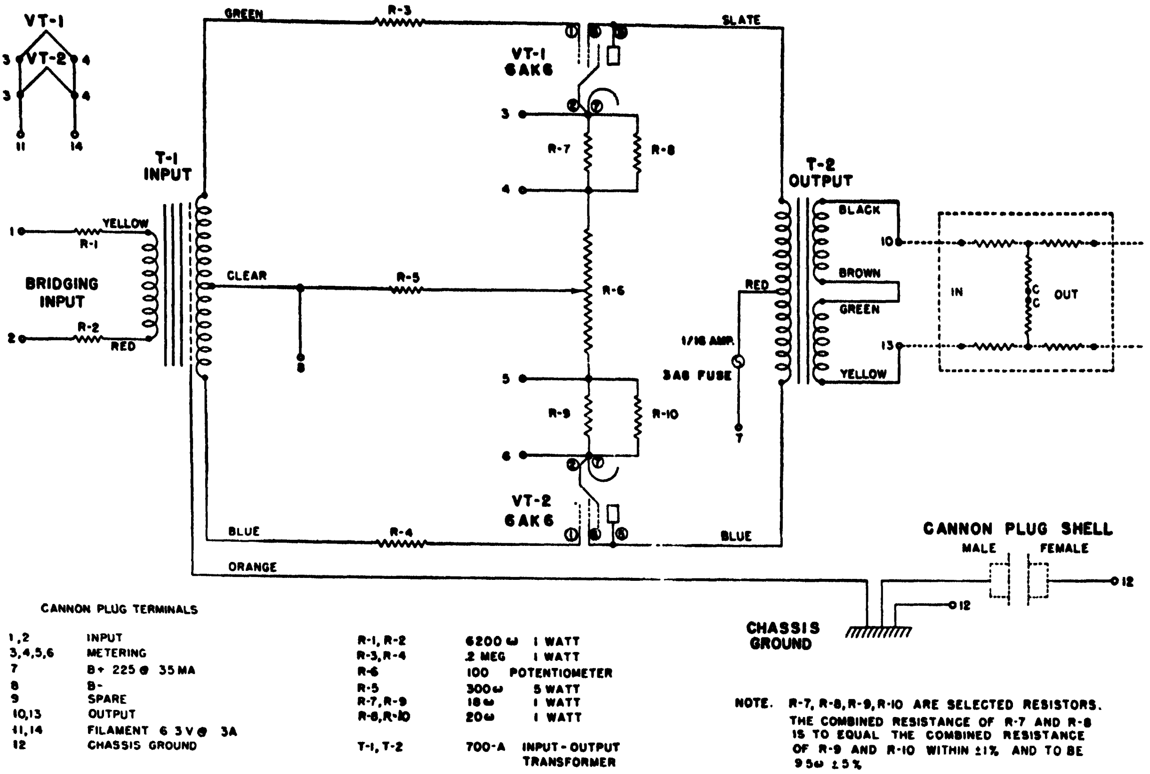


Fig. 9–89. Simplified block diagram of typical master control audio facilities.



CANNON PLUG TERMINALS

1,2	INPUT
3,4,5,6	METERING
7	B+ 225 @ 35 MA
8	B-
9	SPARE
10,13	OUTPUT
11,14	FILAMENT 6 3 V @ 3A
12	CHASSIS GROUND

R-1, R-2	6200 ω	1 WATT
R-3, R-4	.2 MEG	1 WATT
R-6	100	POTENTIOMETER
R-5	300ω	5 WATT
R-7, R-9	18ω	1 WATT
R-8, R-10	20ω	1 WATT
T-1, T-2	700-A	INPUT-OUTPUT TRANSFORMER

NOTE. R-7, R-8, R-9, R-10 ARE SELECTED RESISTORS. THE COMBINED RESISTANCE OF R-7 AND R-8 IS TO EQUAL THE COMBINED RESISTANCE OF R-9 AND R-10 WITHIN ±1% AND TO BE 95ω ±5%

FIG. 9–90. Schematic diagram of Langevin 118A bridging amplifier.

9–50d. Mounting—The small physical size of the 118–A amplifier makes it an ideal unit when it is necessary to transmit program material to many radio lines from a single program bus. Twelve of these amplifiers may be mounted in 10½ inches of rack space as illustrated in Figure 9–91.

9–51. Broadcast Pick-ups from Remote Points—Many radio broadcasts, such as sporting, news, or other special events, as well as musical pick-ups from restaurants, hotels, and night clubs, obviously cannot originate from a radio studio. Portable audio facilities are therefore required which can be carried to the point of program origination and set up quickly and conveniently. The program is then transmitted to the radio station by means of telephone program loops.

Other pick-ups are frequently encountered, such as broadcasts from airplanes, ships, or isolated points, where telephone lines cannot be employed for transmission. In these cases, low-powered radio transmitters are employed to relay the program to a suitable receiving location near the radio station, or to a point where radio program lines to the station are available.

Portable audio facilities for broadcast pick-ups should be small in size and light in weight, to facilitate handling during transportation. In addition, they should be of very rugged construction to withstand the rough handling normally encountered in the field.

The performance of portable equipment should be comparable to the performance of regular studio equipment. Sufficient gain should be provided to permit the use of low-level microphones. The response-frequency characteristics should be uniform and the distortion and noise level should be as low as possible. Facilities employing high-level mixing will have a lower noise level than those employing low-level mixing.

The portable facilities should provide a sufficient number of mixing positions for the intended purpose and should be equipped with a standard volume indicator for visual monitoring. Headphones are normally used for aural monitoring; therefore a suitable headphone jack should be provided and the volume level to the headphones should be high enough to be heard clearly over the loud background noises encountered at many points of remote program origination.

Portable remote pick-up equipment may be powered either from batteries or from rectified a.c. Battery operation must always be provided for, as the equipment is often operated at points where a.c. is not available. It is also desirable to employ bat-

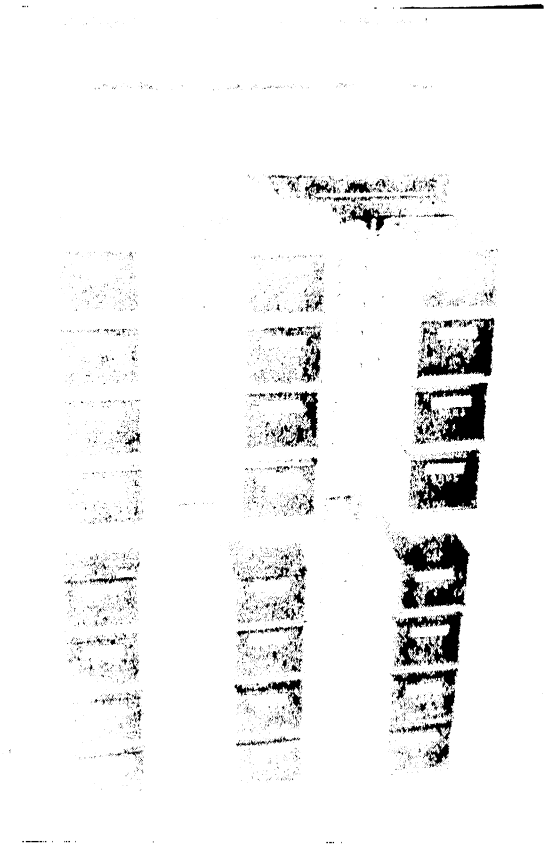


Fig. 9–91. A bank of 24 Langevin 118A bridging amplifiers employed at the United Nations audio facilities at Lake Success. Twelve amplifiers are accommodated in each mounting frame which requires 10½ inches of rack space. Two such frames are shown.

tery operation at any location where there is any possibility of the a.c. failing during the progress of a program.

9–52. RCA Remote Pick-up Equipment OP–6/OP–7—The RCA OP–6/OP–7 is a lightweight, portable pick-up mixer and amplifier providing four microphone inputs with high-level mixing, built-in a-c power supply, and full-sized VU meter. Small cases furnished with shoulder straps provide a maximum of convenience in carrying these units. Battery operation may be used at any time by plugging in the cord of the battery box. No circuit changes are required.

The OP–6/OP–7 combination is illustrated in Figure 9–92. As can be seen, the equipment is divided into two units: the OP–7, a four-position pre-amplifier and mixer; and the OP–6, a high-gain amplifier that raises the low output level of the mixer unit to a level suitable for transmission over wire lines. Where only one microphone is required, the OP–6 may be used without the OP–7 unit.

9–53. RCA OP–6 Portable Remote Amplifier—The OP–6 remote amplifier is designed for broadcast applications at remote service points. Except for certain accessories, such as microphones, monitor headphones, vu meter, and tubes, this unit constitutes a complete equipment. The amplifier is a three-stage, resistance-coupled unit, having linear characteristics, designed to amplify the output of a microphone to a level suitable for telephone line transmission. The amplifier is a single-channel unit, having provision for one microphone, which may be of the velocity, pressure, or unidirectional type. Terminals also are provided for an auxiliary microphone. By changing the input circuit, as described later, a crystal microphone may be used.

The amplifier circuit uses two feedback circuits, one in the first stage and the other in the last two stages. The volume control is arranged to maintain automatically the greatest amount of feedback in the first stage, consistent with the required gain. Distortion resulting from high inputs overloading

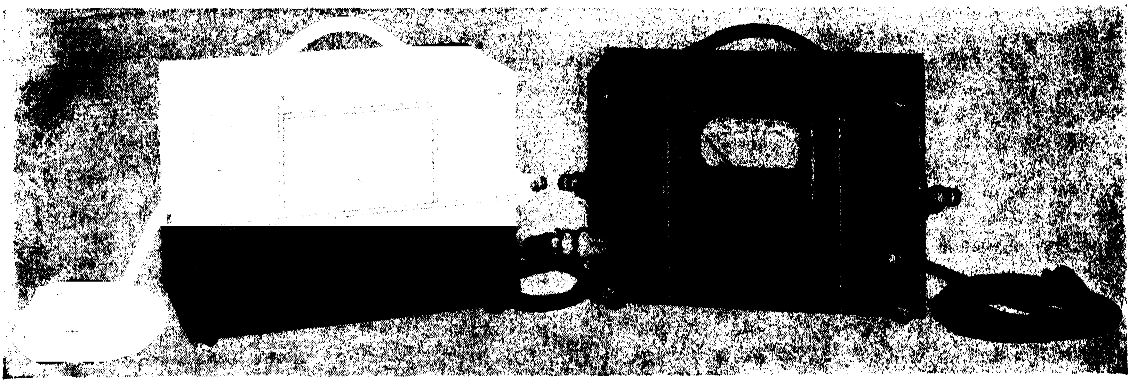


FIG. 9-92. The RCA OP-6/OP-7 remote pick-up equipment. The unit at the left is the OP-7 four-position pre-amplifier mixer. (Courtesy RCA.)

the first stage is reduced by using this circuit design. A 2-db pad in the output isolates the output stage and the telephone line so that the output stage and volume indicator work into a reasonably constant impedance at all times.

The OP-6 amplifier is designed to operate from a-c power lines. However, when so desired, a battery box may be used to furnish power to the amplifier. Switching between a-c line operation and battery operation is accomplished by two power cords, each equipped with a multiconductor plug. The plugs are so connected internally that one cord is used for a-c power supply operation and the other cord for battery operation.

9-53a. Installation

1. *Location and Mounting.* The OP-6 amplifier is self-contained and is adapted especially for use in the remote pick-up (with suitable microphones) of sporting events, street programs, political and social meetings, and other gatherings of a similar

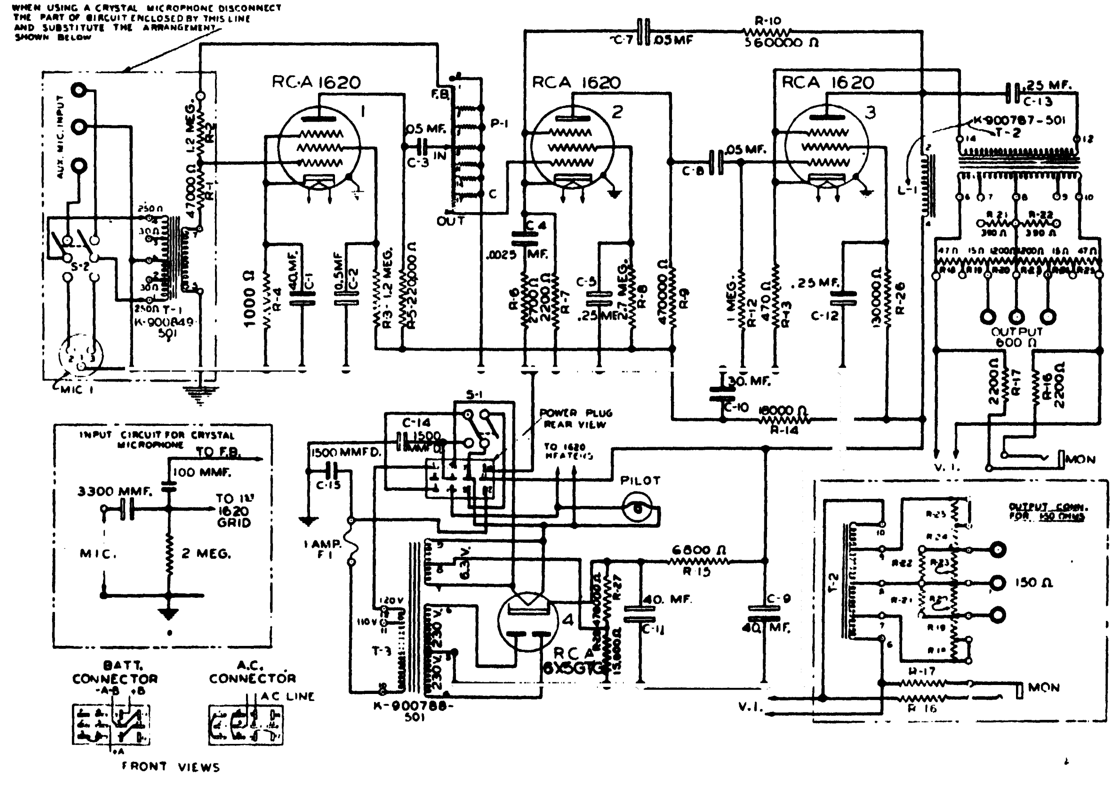


FIG. 9-93. Schematic diagram of RCA OP-6 portable remote amplifier. (Courtesy RCA.)

nature. It also may be used for semipermanent installations. The amplifier may be carried by means of the shoulder strap supplied, or may be placed on any suitable, convenient support. Because of the high gain of this amplifier, care should be exercised to prevent undesirable pick-up when using the amplifier in strong r-f fields or near-by a-c power lines.

2. *Audio Input Connections.* Two input connections are provided: the one (MIC 1) equipped with a Cannon receptacle is for normal operation while the other for auxiliary use (AUX. MIC. 2) is equipped with screw type terminals. A transfer switch marked 1–MIC–2 connects either microphone input to the input transformer. When using a Cannon connector, the cable shield should be connected to terminal 1. When using the auxiliary microphone, the cable shield should be connected to the middle terminal.

If it is intended to use a crystal microphone, the input circuit should be changed as shown on the schematic diagram, Figure 9–93, under the heading "Input Circuit for Crystal Microphone." Either terminal (2 or 3) in the receptacle may be used for the high side of the microphone line as long as it is consistent with the wiring of the microphone to the Cannon plug.

3. *Audio Output Connections.* The OP–6 amplifier is supplied with the output connected for a load (or line) impedance of 600 ohms. The middle output terminal is connected to the center tap of the output transformer. This middle terminal should be connected to the shield (or ground) of the balanced line into which the amplifier is intended to work. The output of the amplifier may be made to work into a load of 150 ohms by changing the wiring as shown on Figure 9–93 under the heading "Output Connections for 150 Ohms." No additional parts are required to make this change.

4. *Battery Connections.* The battery box is designed to be used with the OP–6 amplifier for battery operation. This battery box contains space for 15 Burgess type 4F A batteries or equivalent, and six Burgess type B–30 B batteries or equivalent. This supplies a plate voltage of 270 volts d.c. and a filament voltage of 7.5 volts d.c. The battery box is wired with plugs ready to be inserted into the above-named batteries, and is supplied with a power cord for direct connection to the OP–6 amplifier. The battery connector plug is wired as shown in the lower left corner of Figure 9–93. Where battery life is more important than a small reduction in performance, it is possible to use 6W7–G tubes in the second and third stages.

9–53b. Operation—When the amplifier is set up for use, care should be taken that it is not near a-c power lines or in strong a-f or r-f fields. Particular care should be taken in placing the microphones and microphone cables. When the equipment has been set up for operation, turn the power switch ON and, before broadcasting has commenced, turn the volume control on full, and check carefully for extraneous noises.

Output level to the line should be approximately +8 *vu* and should be indicated properly on the volume indicator. The volume control should be adjusted so that the peaks of modulation swing the needle of the volume indicator to zero on the meter scale (for a line level of +8 *vu*).

9–53c. Maintenance—The volume control contacts should be cleaned by applying Davenoil to the contacts, rotating the knob and, if any dark streaks appear, wiping off the contacts. Repeat this procedure until absolutely clean, then lubricate with a thin film of Davenoil. No other cleaning agent, such as carbon tetrachloride, should be used.

9–54. RCA OP–7 Portable Mixer Preamplifier—The OP–7 portable mixer preamplifier constitutes a complete portable mixer equipment for broadcast applications. It includes four separate preamplifier channels with separate controls for mixing the microphone inputs. From one to four microphones may be used, and they may be of the velocity, inductor, or dynamic types with an impedance of either 250 or 30 ohms. Each of the four channels has a linear characteristic. The OP–7 mixer preamplifier is designed to be used with the type OP–6 amplifier, but may be used with any other similar amplifiers having a 250- or 30-ohm input.

This mixer preamplifier is designed to operate from a-c power lines. However, when desired, a battery box may be used to furnish power, and, if the OP–6 amplifier is used along with the OP–7, the battery box may be used to supply power to both amplifiers. Switching between a-c line operation and battery operation is accomplished by means of two power cords, each equipped with a multiconductor plug. The plugs are so connected internally that one cord is used for the a-c power supply operation and the other cord for battery operation.

The battery box is designed to accommodate the required A and B batteries with additional space provided for the storage of spare tubes, a microphone, and connecting cables.

The input circuit to each of the four channels of the type OP–7 mixer preamplifier consists of a transformer normally connected for 250-ohm operation (30-ohm terminals are available as described under "Audio Input Connections"). An RCA 1620 (or RCA 6J7), connected as a triode, is used in each channel. An attenuator, connected across the primary of the output transformer, is in the output circuit of each tube. The OP–7 mixer preamplifier is designed to insure minimum cross-talk, hum, and distortion.

9–54a. Installation

1. *Location and Mounting.* The OP–7 mixer preamplifier is self-contained and is suited especially for use with the OP–6 (or similar) amplifier when

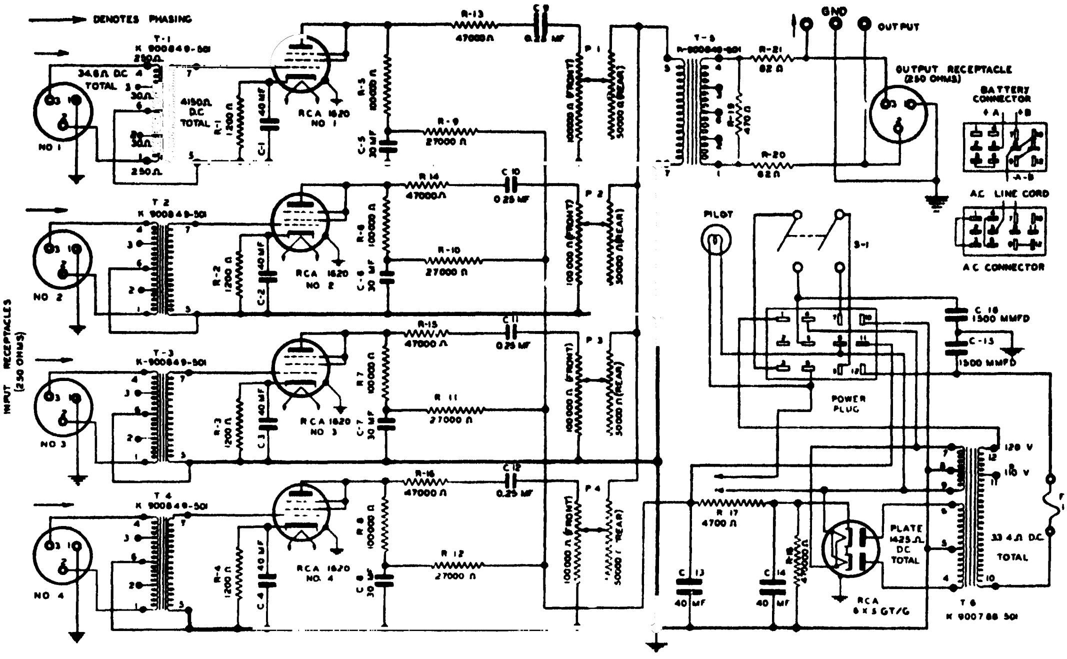


Fig. 9–94. Schematic diagram of RCA OP-7 portable mixer pre-amplifier. (Courtesy RCA.)

more than one microphone is to be used in the remote pick-up of sporting events, street programs, political and social meetings, and other gatherings of a similar nature. With the OP-7 mixer pre-amplifier, the program may be faded readily from one to any other microphone.

When used with a high-gain amplifier, such as the OP-6, due care should be exercised when using the amplifier in strong r-f fields or near-by a-c power lines in order to prevent undesirable pick-up.

2. *Audio Input Connections.* The OP-7 mixer preamplifier is provided with four microphone positions and four mixers. The microphone connections are made through four locking receptacles provided at the rear of the amplifier.

It should be noted that the OP-7 mixer pre-amplifier is provided with four 250-ohm input circuits for use with one to four 250-ohm microphones. If it is desired to use one or more 30-ohm microphones, the same number of microphone receptacles must be disconnected from the 250-ohm primary of their respective input transformers (terminals 1 and 4) and connected to the 30-ohm primary terminals (2 and 3).

3. *Audio Output Connections.* Audio output connections are made through a locking type plug provided at the rear of the amplifier, or connections may be made through three screw terminals on the front panel. To use two OP-7's with one OP-6, the OP-7's should be connected in parallel at the three screw terminals on the front panel marked OUTPUT. A shielded rubber-covered cable such as used for microphones is recommended. The shield should be connected to the center (the ground) terminal on each unit. The OP-7 is connected normally to work into a balanced load of 250 ohms (or higher) such as the input of the type-OP-6 amplifier. However, if it is desired to work into a balanced load of 30 ohms, the output plug (and binding posts) must be disconnected from the resistors R-19, R-20, R-21 and the 250-ohm secondary of the output transformer T-5 (terminals 1 and 4) and connected directly to the 30-ohm terminals (2 and 3). Operation into an unbalanced load is satisfactory provided care is exercised in selecting properly shielded cable.

4. *Battery Connections.* The MI-11214 battery box is designed to be used with the OP-7 for battery operation. This battery box contains space for 15 Burgess type 4F A batteries or equivalent, and six Burgess type B-30 B batteries or equivalent. This supplies a plate voltage of 270 volts d.c. and a filament voltage of 7.5 volts d.c. The battery box is wired with plugs ready to be inserted into the above-named batteries, and is supplied with a power cord for direct connection to the OP-7.

9-54b. Mixer Controls and Operation—Four mixers, numbered from 1 to 4, are provided on the front of the panel for mixing the microphone inputs. The numbers of the mixers correspond with the numbers near the microphone receptacles. When using the OP-7 with the OP-6 (or similar) amplifier, the best signal-to-noise ratio is obtained when the OP-7 is operated with the output level at or near maximum gain.

When the equipment is set up for operation, turn the power switch ON and, before broadcasting has commenced, turn all volume and mixer controls being used on full, and check carefully for extraneous noises. Care should be taken that the amplifiers, microphones, and microphone cables are not near a-c power lines or in strong a-f or r-f fields.

9–55. Electrical Transcriptions—Electrical transcriptions, as well as phonograph records, are very frequently employed as sources of program material in radio stations. It is essential that only the very finest equipment be employed in reproducing these recordings if satisfactory results are to be obtained and objectionable "wows" and "rumble" not introduced. Wows are caused by speed variations in the turntable,[12] while rumble is caused by mechanical vibration being transmitted to the turntable from either the driving motor or from some external source. The transcription-reproducing equipment must be capable of reproducing both "vertical" and "lateral" cut recordings. In lateral recordings, the modulation on the record groove is cut in a direction parallel to the record surface, while in vertical recordings (sometimes called "hill and dale recordings") the modulation is cut at right angles to the plane of the record surface. Phonograph records are all lateral cut, but commercial electrical transcriptions employ both methods.

The recorded response-frequency characteristic of both electrical transcriptions and phonograph records has not yet been standardized and several different characteristics are currently employed. It is therefore essential that an equalizer, capable of adjusting the characteristics of the transcription reproducing equipment to complement the different recorded characteristics, be included. If such an equalizer is not provided, it will be impossible to reproduce properly all recordings.

The pick-up head should be of rugged construction to provide continuous high-quality performance, without failures, under the rigorous service of daily operation for long periods. In addition, the pick-up head should embody the following essential properties.

1. Low stylus force, to reduce record wear.
2. Stylus of correct shape to fit record groove properly.
3. Good response characteristics.
4. Low harmonic and intermodulation distortion.
5. Low acoustic radiation or needle talk.
6. High degree of compliance over the entire frequency range in the direction of stylus motion.

Pick-up heads meeting the above requirements invariably have a very low output level, the output usually being of a magnitude comparable to microphone output levels.

In the following paragraphs, two commercially available transcription-reproducing turntables together with their associated pick-up heads and equalizing equipment are described. This material has been taken from the manufacturer's instruction books.

9–56. Western Electric 109 Type Reproducer Group—The Western Electric 109 reproducer group is a professional disc-record reproducing combination, consisting of a versatile single-element 9 type reproducer with its supporting arm and equalizer equipment. It is a practical reproducer for both vertical and lateral-cut disc-type recordings. Many 109 reproducer groups are in daily use in broadcasting stations, sound distribution systems, wired program service, and general purpose applications.

The 109 reproducer group is available in two combinations. The 109AA reproducer group consists of: 9A reproducer, 5A reproducer arm, KS–13386 equalizer and cable assembly, 171A repeating coil, and 711A bracket. The 109B reproducer group consists of: 9B reproducer, 5A reproducer arm, KS–13386 equalizer and cable assembly, 171A repeating coil, and 711A bracket.

The two reproducers, 9A and 9B, differ only in stylus material and tip radius. They are mechanically and electrically interchangeable on the 5A reproducer arm, and they function equally well with other components of the group. The 9A reproducer has a 2-mil radius diamond tip stylus. It gives good performance and long life on transcription type records made of nonabrasive material. It is suited for vertical and lateral cut records with narrow or medium groove cross section. The 9B reproducer has a 2½-mil radius, sapphire-tip stylus. The larger stylus tip improves the signal-to-noise ratio of the lateral recordings with wider groove cross sections. When used with records containing an abrasive (phonograph records), the sapphire may, in time, wear sufficiently to alter reproduction. However, stylus renewal can be obtained by returning the reproducer to the distributor.

9–56a. 9 Type Reproducer—The W. E. 9 type is a dynamic (moving coil) type reproducer with the pick-up stylus arranged to move vertically for reproduction from vertical records and transversely for reproduction from lateral records. This instrument provides excellent discrimination between the two different types of groove modulation. The vertical noise components always present in lateral record grooves are suppressed when the reproducer is switched for lateral reproduction. Correspondingly, when the reproducer is switched for vertical reproduction, unwanted lateral modulation, inherent in the sides of vertical record grooves, is suppressed.

The 9 type reproducer and associated 5A reproducer arm have been designed so that their natural period of resonance lies below the audio frequencies usually reproduced in any program system. This,

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[12] Speed variations are not the only cause of wows. They are also brought about by eccentricity of the center hole in the record, a loose fit of the centering pin in the center hole of the record, and by a wobbly turntable.

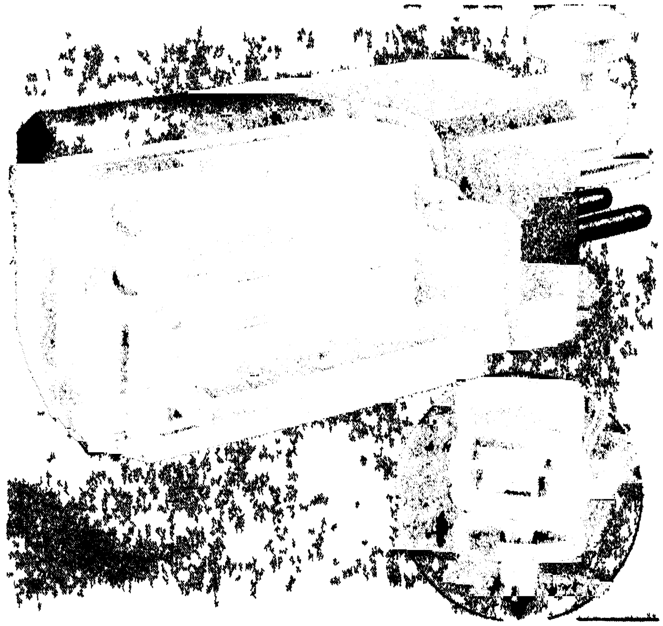


FIG 9–95 A cut away view of the Western Electric 9 type universal phonograph reproducer reveals its unique use of two balanced coils Note also the four prong terminals (extreme right of upper figure) by means of which the electrical phase of the coils may be switched 180° when shifting from vertical to lateral recordings The small insert shows an enlarged view of the vibrating system The circular vane of viscous material carried by the stylus support damps out high frequency resonances caused by the elastic properties of the record material (Courtesy Western Electric)

together with the low mechanical impedance of the 9 type reproducer minimizes unwanted vibratory pick up and enables the full range of groove modulation to be reproduced faithfully The jewel stylus tip and the extremely light pressure on the record (only 35 grams) assure long record life

9–56b. 5A Reproducer Arm—Weighing 3½ pounds, the 5A reproducer arm has sufficient mass to offer the inertia essential to stable tracking and full low-frequency reproduction The 5A reproducer arm has a four-pin jack into which either of the 9 type reproducers may be plugged The reproducer is locked in position by means of a thumbscrew The arm supports and counter-balances the reproducer and contains leads for connection to the KS–13386 equalizer and cable assembly

The over-all length of the arm and reproducer is 18½ inches and the distance between the stylus and pivot is 13⅛ inches Height of the arm is adjustable to accommodate different heights of turntable platters (¾ inch to 2 inches) The height is easily adjusted by means of a set screw and should be adjusted for each installation so that the stylus is perpendicular to the record

9–56c. KS–13386 Equalizer—The KS–13386 equalizer (and cable assembly), and the 171A repeating coil form the equalizing, switching, and impedance-matching portion of the 109 type reproducer groups The equalizer switch has seven reproducing positions two for vertical and five for lateral The seven reproducing characteristics are based on two fundamental frequency response characteristics, Curve A and Curve B These curves match those which are currently used for record production Curve A is the conjugate of the frequency response curve in general use in recording vertical transcriptions, some early lateral transcriptions and a few "instantaneous type" lateral trans-

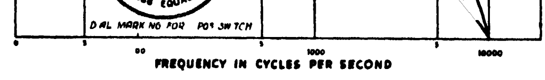


FIG 9–96 Reproducing characteristics of the Western Electric 109 type equipment

scriptions. Curve B is the conjugate of the frequency response curve in general use in recording lateral transcriptions (NAB Standard and Orthacoustic) and phonograph records. For information on specific curves used in making recordings, the recording studios should be consulted.

9-56d. 171A Repeating Coil—The 171A repeating coil provides taps for feeding circuit impedances of 30 ohms, 250 ohms, or 500/600 ohms. This must feed directly into a resistive type circuit such as a constant-impedance type mixer. For faithful reproduction when feeding high-impedance circuits, such as a preamplifier input, a simple L pad should be interposed between the repeating coil and the preamplifier for purposes of impedance stabilization.

9-56e. Wiring Connections—Connections between reproducer and switch, and switch and repeating coil, should be made as shown in Figure 9-97. All equipment and wiring should be located as far as possible from the motor and power wiring.

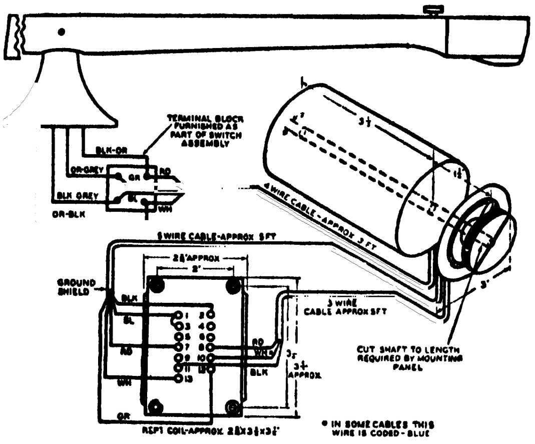


Fig. 9-97. Inter-component connection of the Western Electric 109 type reproducing equipment.

The input circuits with which this reproducer group is connected should be operated unbalanced with respect to ground and should be connected to the 171A repeating coil as follows:

For 30 ohms: use terminals 3 (ground side) and 4.

For 250 ohms: use terminals 3 (ground side) and 5.

For 500/600 ohms: use terminals 3 (ground side) and 6.

The coil is designed to work into a resistive load. It can be connected directly to a constant-impedance mixer circuit. When it is connected to a preliminary amplifier input, a pad must be used between the repeating coil and the amplifier to stabilize impedance conditions. Typical connections are shown in Figure 9-98. If the amplifier is operated with one side of its input circuit grounded, for best results the grounded side should be connected to terminal 3 of the repeating coil.

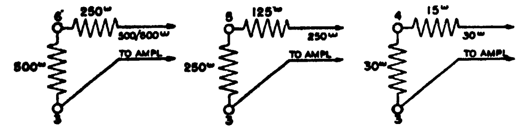


Fig. 9-98. Termination network required on 171A repeating coil when feeding a high-impedance circuit, such as a preliminary amplifier input.

9-56f. Technical Data

1. *Frequency response*

For representative transmission from input to recorder filter to output of reproducer group, see Figure 9-96.

For new transcriptions, use Curve A, V1 or L1 positions.

For old or worn transcriptions, use Curve A, V2 or L2 positions.

For phonograph records, use Curve B, L2 or L3 positions.

For phonograph records having low surface noise, use Curve B, L1 or L2 positions.

2. *Output noise:* Dependent on record. Experience indicates that representative signal-to-noise ratios as high as 45 db for transcriptions and 20 db for phonograph records are attainable under operating conditions.

3. *Operates from:* Vertical or lateral-cut disc records up to 16 inches in diameter.

4. *Load impedance:* 30, 250, or 500/600 ohms mixer or stabilized preamplifier input. Reproducer group must be operated into a proper resistive termination.

5. *Output level:* Dependent on record. Representative program level comparable to high-quality microphone output level. Experience indicates that a net gain of 60 to 80 db is adequate to raise the level to 0 *vu*.

9-57. RCA Type 70-C2 Transcription Turntable—The type 70-C2 transcription turntable is designed for high-fidelity reproduction from records and transcriptions. Mounted on the turntable is a combination pick-up and arm assembly for use in reproducing both lateral- and vertical-cut records. None of the turntable components overhangs the edges of the cabinet, so that the cabinet may be placed against a wall. A removable door on the front of the cabinet permits easy access to the motor, filter and terminal boards. There is sufficient space within the cabinet to mount a booster amplifier. The motor is a high-torque synchronous type, cushion-mounted on the bottom shelf of the equipment. The turntable has associated with it a separate flywheel to insure excellent speed regulation. The a-c power switch is a mercury-tube of the tumbler type. This silent type of power switch, mounted atop the cabinet, permits the turntable to be operated near a microphone. A speed-change switch near the edge of the turntable plate is used to select either 78- or 33⅓ rpm for the turntable speed.

The pick-up and filter reproduce the various types of records (Orthacoustic, Victor, RCA, Columbia, World and others) with a response characteristic which is considered an ideal play-back response. The filter unit is designed so that this may be accomplished by turning a switch to one of six positions. The pick-up head is of the moving-conductor type in which two ribbons are free to vibrate in their respective magnetic fields. The phase relation of the voltage generated in the ribbons reverses 180° when changing from reproducing lateral records to vertical records. The filter unit in the output circuit selects the proper circuit so that the output voltages will be additive for either type of record. Since any vertical modulation will be cancelled when playing lateral-cut records, the "pinch-effect" in lateral reproducing is cancelled. (Pinch-effect is due to cutting a record with a plane and reproducing with a spherical surface. This produces second-harmonic frequencies which would seriously affect the quality of reproduction if not cancelled by the pick-up filter circuit.) The pick-up head contains a diamond-point stylus to eliminate the necessity of changing styli. The pick-up filter is designed to work directly into the primary of an unloaded input transformer.

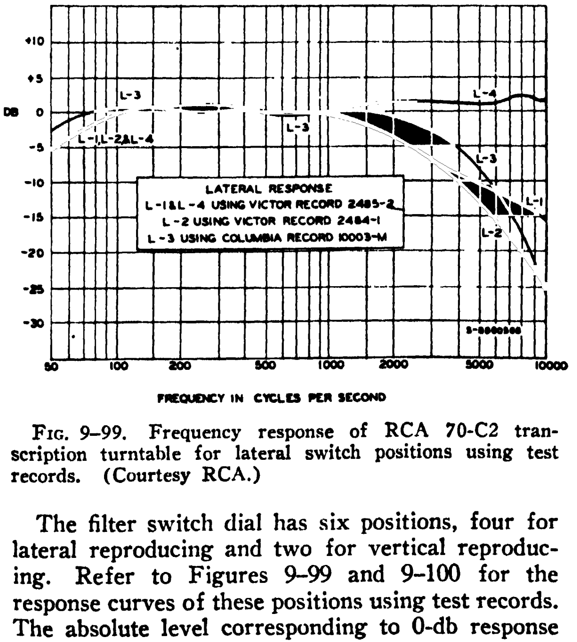


Fig. 9–99. Frequency response of RCA 70-C2 transcription turntable for lateral switch positions using test records. (Courtesy RCA.)

The filter switch dial has six positions, four for lateral reproducing and two for vertical reproducing. Refer to Figures 9–99 and 9–100 for the response curves of these positions using test records. The absolute level corresponding to 0-db response depends on a number of factors, an important one being the level employed in recording. However, it is probable that a good average is about the same as that accepted for the dynamic microphone on program pick-up, namely, −62 db below 1 milliwatt approximately.

The switch positions are to be used as follows:

1. Swith position L–1: Lateral transcriptions, for reproduction of transcriptions recorded according to the NAB standard lateral characteristic.

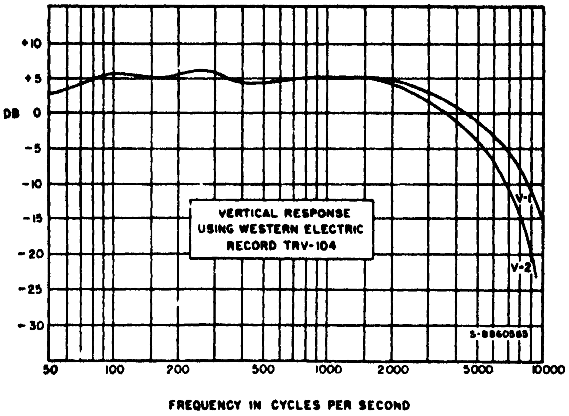


Fig. 9–100. Frequency response of RCA 70-C2 transcription turntable for vertical switch positions using test record. (Courtesy RCA.)

2. Switch position L–2: Phonograph records, for reproduction of records and transcriptions which have been recorded with a cross-over frequency of 500 cycles, such as Victor.

3. Switch position L–3: Phonograph records, for reproduction of records and transcriptions which have been recorded with a cross-over frequency of 300 cycles.

4. Switch position L–4: Flat response, for reproduction of lacquer recordings cut flat, especially when using the automatic equalizer to raise the high-frequency level at the inside of the record. This position may also be used for test purposes.

5. Switch position V–1: Vertical transcriptions, such as World, for reproduction of transcription recordings cut in accordance with the NAB standard vertical characteristic.

6. Switch position V–2: Vertical transcriptions such as Associated, same characteristics as V–1 except less high-frequency response.

In order to insure stability of operation, turn the motor switch ON and allow the turntable to run for at least five minutes before playing a record. This should be done especially when the instrument has been idle for an appreciable length of time (such as overnight or when the instrument has been exposed to the cold), but it is not essential between operations separated by intervals of short duration. After setting the speed-shifting lever, rotate the turntable platter slowly by hand until the mechanism is heard to engage. Avoid engaging the mechanism by holding the turntable platter and starting the motor.

For close cueing of records, it is satisfactory to hold the record by finger pressure on the rotating platter and to release the record just prior to opening the fader for the turntable channel. This practice may shorten the life of the turntable felt, but a new turntable felt may be ordered which is easily installed.

Another common cueing practice is to locate the pick-up in a starting groove and rotate the record until the program is heard to start either by direct talk-back from the record or through an electrical cue system. Without lifting the pick-up stylus from the record, move the disc back by a portion of a revolution to permit the turntable to come up to speed before the program starts after the motor switch is turned on. This may be over ¼ revolution for 78 rpm records and over ½ revolution for 33⅓ rpm recordings.

As a result of the continued demand for higher quality in the reproduction of broadcast transcriptions, the transcription turntable has been developed, through engineering refinements, into a device in the class with precision instruments and should be treated as such. With reasonable care and proper lubrication, it should give years of constant service without noticeable increase in speed variation.

9-58. Recording Equipment—It is often desirable in radio broadcasting operations to employ recording equipment to record a complete radio program, or a portion of a program, which may then be reproduced for radio transmission at a later time. This is particularly useful in connection with events that occur at a time not suitable for direct broadcasting. If such programs are recorded, they may then be transmitted at any desired time. Another use for such recorded material is in connection with long-distance, short-wave pick-ups. It often happens that short-wave communication conditions are not ideal at the time the broadcast is scheduled. If recording equipment is available, the short-wave portion of the program may be recorded at any time conditions permit prior to the actual broadcast time and then be reproduced during the radio broadcast.

Instantaneous recording, so called because the records can be played back as soon as they have been recorded without any intermediate processing, and without damage to the record, is generally employed for this purpose at radio stations. These instantaneous recording equipments employ the lateral system of recording almost exclusively. The completed recordings can be played back on transcription-reproducing equipment such as described in this chapter.

Described below is a commercially available recorder that is capable of cutting lateral recordings at turntable speeds of 33⅓ or 78 rpm. The text of this material has been taken from the manufacturer's instruction book and, in addition to describing the equipment, contains some discussion of the problems involved in instantaneous recording and the technique of the instantaneous recording art.

9-59. The RCA Type 73-B Professional Recorder—The RCA type 73-B professional recorder is designed to make high-quality disc recordings at either 33⅓ or 78 revolutions per minute. It may be used in applications for preparing masters from which large numbers of records can be made. The recorder is highly suitable for broadcasting stations in recording programs for use on future broadcasts, for rehearsals, auditions and similar applications.

The turntable of the recorder is 17½ inches in diameter and will accommodate blanks up to 18¼ inches in diameter and ⅜ inch thick. A removable rubber mat on the turntable provides a good record base and may be easily cleaned. Near the center of the turntable a drive pin is mounted over which fits any one of three drive holes in the record blank When it is desired to make use of record blanks without drive holes, this drive pin may be pressed down so that it will be below the surface of the rubber mat. A plunger-release button is mounted alongside the drive pin, and when this button is pressed, the drive pin comes back into position.

The turntable is rim-driven by two synchronous motors coupled to drive wheels. Both motors are controlled by one ON-OFF lever which operates a motor switch. When the lever is turned OFF, a brake automatically is applied to the rim of the turntable, bringing it quickly to a stop. The motors are doubly rubber shock-mounted from the motor board.

The feed screw is designed so that the recorder-head carriage may be used for either outside-in or inside-out recordings without changing feed screws. The feed-screw drive consists of a pulley-and-belt system between the drive shaft and turntable spindle. Mounted on the drive shaft above the turntable is a friction wheel which drives a flange on the end of the feed screw. The friction wheel may be moved up and down over the entire diameter of the flange by means of a knob on the outside of the drive-shaft housing. This adjustment selects the recording pitch and the direction of cut. An illuminated pointer and scale on the outside of the drive-shaft housing indicates the setting of lines per inch for both inside-out and outside-in recordings. A release lever mounted at the top of the housing disengages the friction wheel from the flange when turned counterclockwise to facilitate adjustment to the desired number of lines per inch. A spring attached to the friction wheel is adjusted at the factory to provide the proper pressure against the flange when the release lever is in the engaged position (turned clockwise).

A separate self-braking motor overdrives the feed screw to provide start and finishing spirals. This motor is coupled to the feed-screw drive shaft by a pulley-and-belt system. A nonlocking push-button switch near the drive-shaft housing is used

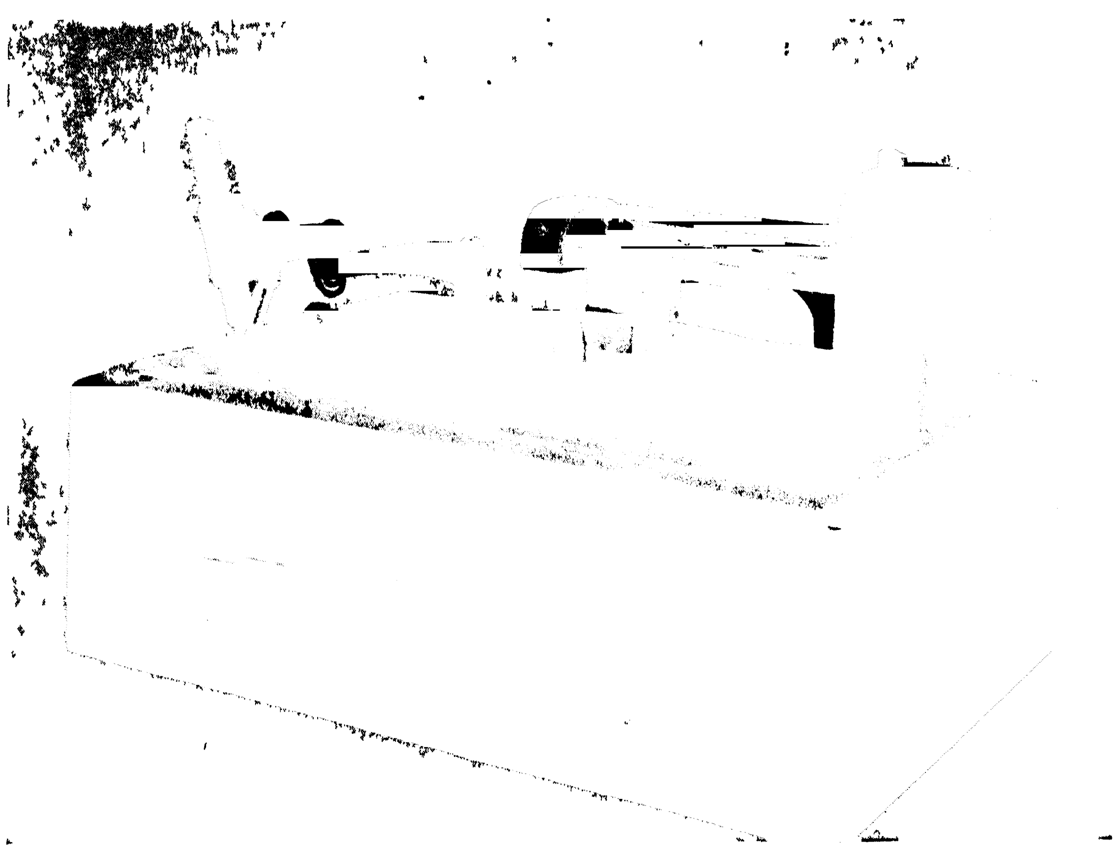


Fig. 9–101 The RCA 73 B professional recorder.

to operate this motor. The spiralling pitch is six lines per inch when the turntable speed is 78 rpm. For a turntable speed of 33⅓ rpm the spiralling pitch is reduced in proportion to the speed change.

The recorder-head carriage is free to rotate about the feed-screw tube until a latch locks the carriage with the feed-screw tube when the carriage is in the raised or non-cutting position. When the carriage is raised from the cutting position, the feed-nut arm automatically disengages from the feed-screw, the arm automatically engages when the carriage is released from the rest position.

The center thumb nut on the carriage controls the angle of the cut. The left-hand thumb nut adjusts the depth of the cutter.

The stylus lowering lever is used to raise or lower the stylus When the carriage is in the standby position, the feed-nut arm is engaged, and the stylus is near the surface of the record, ready to be lowered to the record by operating this lever.

The compensator, transformer, series resistor, high-off-low switch, pilot lamp and receptacle which are recommended for use with the MI-11850-C recorder head are all built into the recorder.

Four timing scales are provided, each calibrated for 96, 104, 112, 120, 128, 136, 144 and 152 lines per inch:

One for inside-out recording at 33⅓ rpm
One for inside-out recording at 78 rpm
One for outside-in recording at 33⅓ rpm
One for outside-in recording at 78 rpm

A high-quality, 36 power microscope with an associated arm assembly is provided for mounting alongside the turntable. The microscope scale is calibrated so that each division represents 0.001 inch on the object viewed. This permits measurement of groove and wall widths of the record face, and by comparison of the dimensions thus obtained with known standards for recording work, and with proper interpretation, superior recordings may be made.

The microscope may be moved over the entire record surface. A small lamp is mounted on the adjustable arm to illuminate the record grooves An off-on toggle switch for this lamp is mounted on the microscope arm.

9–59a. Turntable Operation—After all connections have been made to external equipment, follow the procedure below:

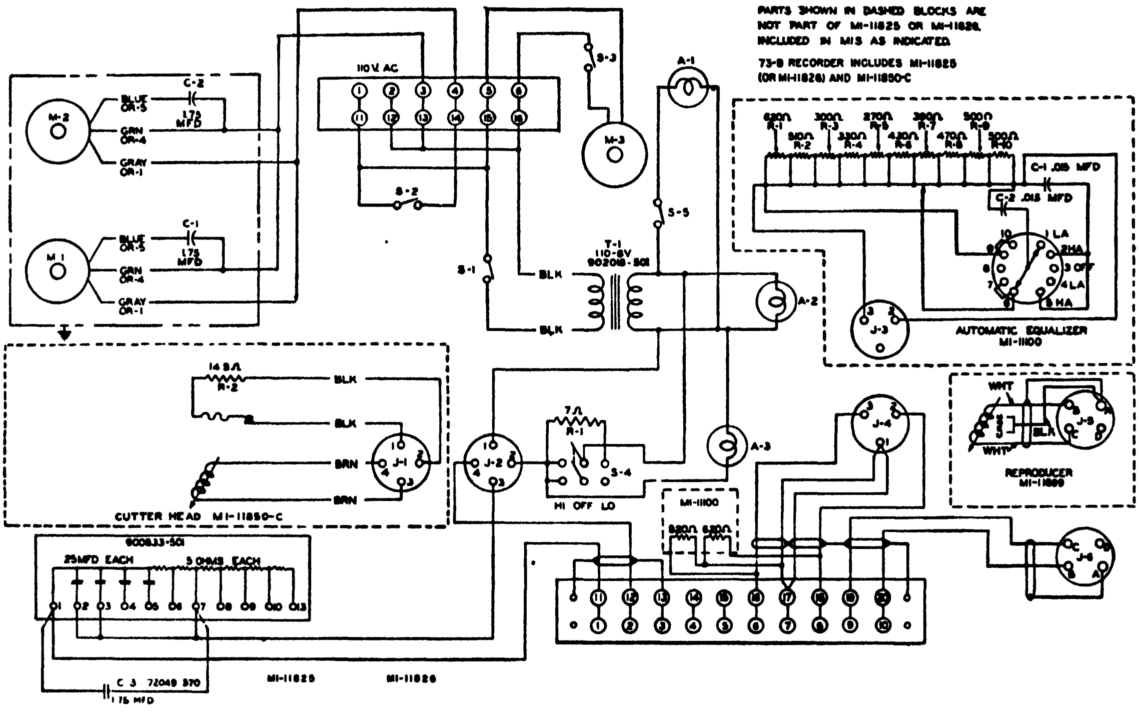


FIG. 9–102. Schematic diagram of the RCA 73-B recorder.

1. With the turntable platter stationary, press plunger-release button near the center of the turntable platter allowing the record-drive pin to come up into position.

2. Place a recording blank on the turntable so that one of the holes in the record fits over the record-drive pin.

3. Be sure the stylus is satisfactory (worn styli should be reground or discarded). Check all styli for form and cutting edge upon receipt from the vendor.

4. Turn ON the master lamp switch.

5. Set the heater switch to the desired position. The HI position short-circuits the 7-ohm resistor in the recorder-head heater circuit for quick warm-up or for operation in ambient temperatures between 40° and 65° F. The heater-indicator lamp is on when this switch is on HI or LOW. In the off position (switch arm vertical), the heater circuit is not energized, and this lamp is off.

6. Turn on the microscope lamp switch.

7. Set the speed-shift control knob to the desired speed position.

8. With the feed-screw drive release lever in the disengaged position (turned counterclockwise), set the lines-per-inch control knob to the desired setting as shown by the indicator on the illuminated scale. Put the release lever in the engaged position (turned clockwise).

9. Rotate the calibrated scale to the proper position to agree with the setting of the speed-shift knob and lines-per-inch setting.

10. Turn ON the motor.

11. With the recorder head in the standby position, press the feed-nut lever and slide the carriage horizontally until it is in the desired position over the record. By means of the stylus-lowering lever, lower the stylus to the record.

12. Set the correct depth and angle of cut by the two knobs atop the carriage.

13. Keep the input signal at the proper strength throughout the recording.

14. To cut a spiral for beginning, ending, or separating portions of a recording, press the spiralling switch. Do not use the spiralling motor continuously for any length of time other than to cut the necessary spirals on the record.

15. At the conclusion of the recording, raise the stylus-lowering lever which lifts the recorder head from the record; then raise the carriage until it locks automatically in the rest position.

16. Turn OFF the motor, and press the lever firmly to stop the turntable. Remove the record.

Caution: When the recorder is not being used, care should be taken to see that the motor lever and switches are OFF and the feed-screw drive lever is in the disengaged position (turned counterclockwise).

9–59b. Maintenance—Two oil holes are provided in each drive motor (one in each end bell) for the lubrication of the motor bearings. Use a light high-grade, non-gumming machine oil, such as SAE-10. Put six or seven drops in each oil hole at intervals of one month. Each oil hole is covered with a ball and spring seal to keep out dirt and dust. To gain access to the oil holes, first remove the cabinet. Use an oiler with a 1/16-inch (maximum) spout. This lubrication may be most easily accomplished from the front and rear of the recorder.

To lubricate the turntable spindle and bearing, use petroleum jelly.

To lubricate the carriage drive-shaft bearings use a non-fluid oil such as "N. Y. and N. J. Lubricant Co. Type K-00 Special Graphited" (RCA dwg. 183440-11).

Note: Do not lubricate the carriage support tube or the feed screw. If these parts become dusty or dirty, wipe them off with a clean dry rag free from lint.

9-59c. RCA High-fidelity Recording Head—The MI-11850-C high-fidelity recording head is a high-quality recording head of the magnetic type. Although primarily designed for recording on composition-coated discs, it is equally satisfactory for use with soft-wax discs, such as are used in commercial recording.

The MI-11850-C recording head consists of a cobalt-alloy permanent magnet, laminated pole pieces, a driving coil, and an armature and damping material assembled in an insulating case which is closed by a bottom cover plate. The armature is supported on knife-edge bearings and held in position by a steel centering spring. Connection to the recording head is made through the attached cable and 4 pin plug assembly.

The MI-11850 recording head is maintained at constant temperature while operating by a self-contained heater and thermostat. The power for heater-operation is obtained from a heater kit supplied as an integral part of the RCA recorder or as the MI-11855-A heater accessory kit. If heater power is not available from these sources, a 7-ohm resistor should be connected in series with the heater to a 6.3-volt a-c source for operation at normal ambient temperatures of 65° to 95° F. The resistor can be short-circuited to provide a quick warm-up when beginning operation. If the recording head must be operated at a lower ambient temperature, down to 45° F, the resistor must be left short-circuited so that a full 6.3 volts are supplied to the heater.

Each of these recording heads is adjusted to close frequency response limits. Individual response curves do not depart from a normal curve by more than 2 db between 30 and 10,000 cycles. However it should be noted that the working load on a cutter increases as the diameter of the recorded groove decreases. The average variation in response of the cutter when recording the largest and smallest recommended groove diameters at 33⅓ rpm, is approximately 1.7 db, at 1000 cycles. The variation may be somewhat more at 10,000 cycles, depending on the individual head. Figure 9-103 illustrates the normal cutter response characteristics when recording on lacquer at an average diameter of 10 inches. Individual recording heads are matched for sensitivity within 2 db at a frequency of 1000 cycles. With the self-contained heater unit functioning correctly, the frequency response is unaffected by ambient temperature changes between 45° and 95° F.

The recording head must never be connected directly to the output terminals of the recording amplifier. A compensator, which acts to maintain the impedance of the cutter approximately constant at

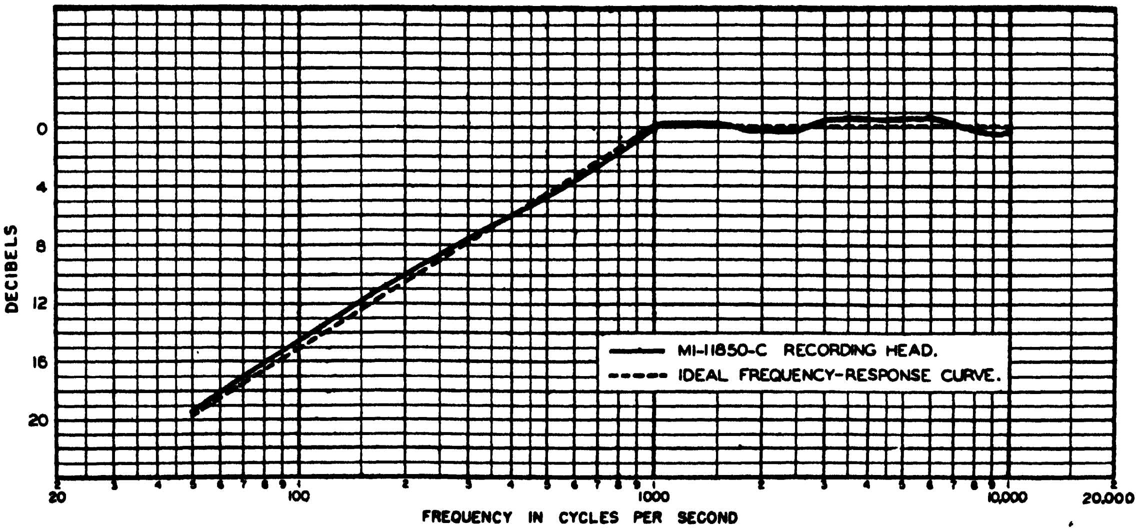


FIG. 9-103. Typical frequency response of MI-11850-C recording head.

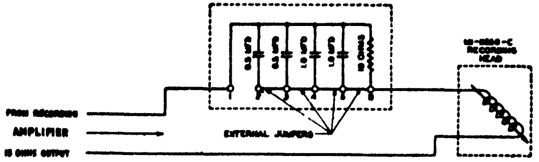


Fig. 9–104. Connections for impedance-correcting compensator.

15 ohms throughout the audible-frequency range, is supplied as a part of the heater kit. The normal connections are shown in Figure 9–104. Critical operators may wish to compensate for slight sensitivity variations caused by manufacturing tolerances in order to obtain identical sensitivity in each of the cutters in use. When this is desired connect external resistance in series with the high-sensitivity units, in steps of not more than one ohm.

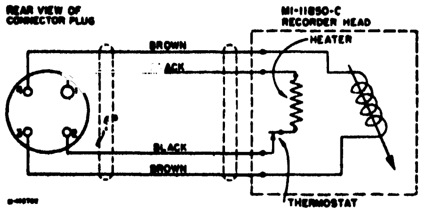


Fig. 9–105. MI-11850-C recording head connections.

9–59d. Associated Equipment

1. *Cutting Styli.* Either the MI-4842 sapphire stylus, with 70 degree angle and short shank or the MI-4878-D with 90° angle and short shank, is recommended for use with this cutting head for recording on acetate-lacquer blanks. If a long-shank stylus is used, records will be approximately 2 db louder for the same recording level, but the frequency response will be poor beyond 8000 cycles and a severe high-frequency peak may develop in this region.

Steel or tungsten styli can be used, but they have a shorter life and are usually not satisfactory for high-fidelity work, since in general they produce a groove having a higher noise level. Sapphire styli are recommended for all recording except unimportant tests. The initial cost is reasonable, and the moderate charge for sharpening makes the cost-per-minute of recording equal to or lower with sapphires than with steel cutters. Sapphires, when sharp and not chipped, hold the groove shape accurately, and produce a groove surface quieter (by 6 db or more) than a surface cut by a steel stylus.

2. *Chip Removal.* Some means should be provided for the removal of the chip or thread produced by the cutting stylus. A vacuum system, such as the MI-4922, is recommended for this purpose, since it will remove the chip easily and quickly without danger of damage to the record. Precautions must be taken, however, to make sure that vibrations from the vacuum system are not transmitted to the cutter head or the recorder assembly, since this will cause serious noise in the recordings.

Care must be taken in the correct placement of the suction nozzle. When recording on lacquer, the nozzle can be placed just in front of, and about ¾ inch nearer the center of the disk than the stylus, although some operators prefer placing the nozzle directly behind the stylus. The nozzle must be slightly closer to the stylus when cutting wax. If the nozzle is too close to the surface of the record or the air velocity is too high, a noisy cut will result.

The vacuum for normal operation should be about 1½ inches of mercury. Under ideal conditions it may be possible to reduce this somewhat. Tests have shown that a vacuum of 1 inch mercury is about the minimum that will pick up the chip initially and that about ½ inch is necessary to maintain the pickup under the best conditions.

When a vacuum system is not available, other means must be considered for removing the chip. When cutting from the inside out, the chip is naturally thrown toward the grooves that have already been cut, so that its removal does not present too great a problem. When cutting from the outside in, however, the chip is thrown into the path of the cutter and must be kept clear at all times or the cutting stylus will be fouled and the record ruined. Some operators use a soft brush, keeping the record clear by brushing the chip carefully toward the center of the disk. Great care must be taken not to mar the record surface, nor to alter the speed of the turntable, since "wows" will result in the recording. Brushing the chip is not, however, considered good practice when the best results are desired.

3. *Amplifiers.* For ordinary work, an amplifier having a uniform frequency response from 30 to 15,000 cycles and capable of an undistorted power output of 12 watts, used in conjunction with an MI-4916 orthacoustic recording filter, is a satisfactory source of power for driving the MI-11850-C recorder head. Some recommended arrangements for typical record channels are illustrated in Figure 9-106. If the input source is a program channel, the set-ups shown in A and B of Figure 9–106 will give good results. If it is desired to match the program channel into the recording set-up, an arrangement similar to A of Figure 9–106 can be used, except that an isolation transformer of correct impedance must be substituted for the bridging transformer, and the 600-ohm pad must have about 25-db loss instead of 15-db loss. Make sure that the resistors marked X and Y are included at the positions shown, since these prevent resonance between the recording filter and the windings of the transformers. The set-up shown at C of Figure 9–106 can be used when recordings are to be made directly from the studio microphones. It is important that the input level into the MI-4916 recording filter be kept down to about − 30 dbm, to prevent

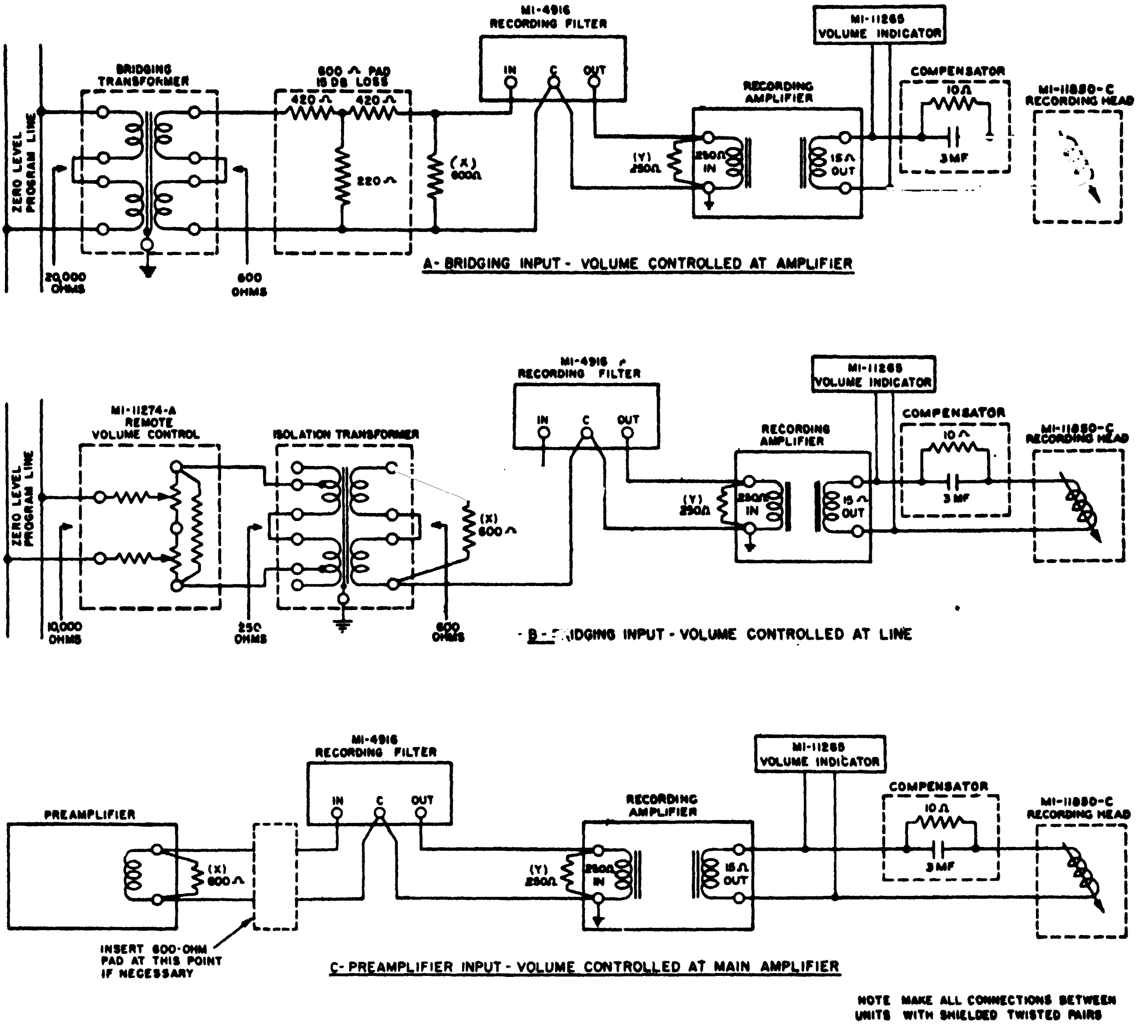

MI-4916 RECORDING FILTER
MI-11265 VOLUME INDICATOR
BRIDGING TRANSFORMER
600 Ω PAD 15 DB LOSS
420 Ω
420 Ω
220 Ω
(X) 600Ω
IN
C
OUT
RECORDING AMPLIFIER
(Y) 250Ω
250Ω IN
15Ω OUT
COMPENSATOR
10Ω
3MF
MI-11850-C RECORDING HEAD
ZERO LEVEL PROGRAM LINE
20,000 OHMS
600 OHMS
A- BRIDGING INPUT - VOLUME CONTROLLED AT AMPLIFIER
MI-11274-A REMOTE VOLUME CONTROL
ISOLATION TRANSFORMER
(X) 600 Ω
10,000 OHMS
250 OHMS
600 OHMS
B- BRIDGING INPUT - VOLUME CONTROLLED AT LINE
PREAMPLIFIER
INSERT 600-OHM PAD AT THIS POINT IF NECESSARY
C- PREAMPLIFIER INPUT - VOLUME CONTROLLED AT MAIN AMPLIFIER
NOTE MAKE ALL CONNECTIONS BETWEEN UNITS WITH SHIELDED TWISTED PAIRS

FIG. 9–106. Typical recording setups.

overload of the first stage of the recording amplifier. This may require the insertion of a 600-ohm pad similar to the one shown in A of Figure 9–106, immediately after the preamplifier. When the pad is used make sure that resistor X is disconnected from the output of the preamplifier and connected after the pad as shown in A.

When masters for processing are to be recorded, it will be advisable to use an amplifier having a greater power output in order to accommodate higher peaks without distortion. A rated power output of at least 50 watts is recommended. When the amplifier is not equipped with built-in compensation the MI–4916 orthacoustic recording filter can be connected ahead of the amplifier as described in the preceding paragraph. A limiting amplifier can be used to drive the recording amplifier when limiting of the peak voltages is desirable.

4. *Monitoring.* In view of the extended frequency range of this recording head, the program quality during recording should be judged by means of an equally wide-range monitor system. For best results it is recommended that an independent monitor system be used.

This is good practice, since it avoids the distortion caused when the monitor loud-speaker and the recording head are driven by the same amplifier. (The recording amplifier is usually compensated at the high-frequency end, either internally or by means of a preceding filter, and for this reason makes a poor source of power for the monitor speaker.)

Unless the monitor system adequately covers the entire audio range, it is impossible to determine if the program being recorded is free from distortion. Some programs received over long lines contain considerable distortion compared with those from local studios. The distortion might easily remain unnoticed on a monitor system of limited range, but would probably show up in high-fidelity recordings of the same program, when played through a wide-range playback channel.

9-59e. Operation

1. *Duplication Methods.* Much .of the popularity of the so-called instantaneous recording has come as a result of successful duplication of records. When only a few copies are required, these can ordinarily be made by re-recording, with little impairment of quality.

If a larger number of copies are desired, the original master can be processed by silvering or gold sputtering, and a stamper produced. Pressings can then be obtained in a variety of materials, depending upon the particular requirements involved.

2. *Recording Blanks.* In order that the best results may be obtained, it is essential that recording blanks of the best quality be used. Warped blanks or blanks having excessive swirls or defects in the lacquer surface should be rejected or set aside for tests or unimportant recordings.

When pressings are to be made, special blanks of increased diameter and thickness are required. The maximum diameter of the recorded grooves must not exceed that of standard pressed discs, the extra outer portion of the master discs being left blank to permit holding during the processing.

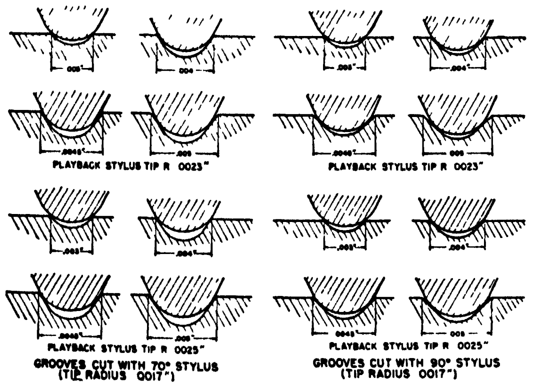

.003"
.004
.003"
.004"
.0045"
.005
.0045"
.005
PLAYBACK STYLUS TIP R .0023"
PLAYBACK STYLUS TIP R .0023"
.003"
.004"
.003"
.004"
.0045"
.005"
.0045"
.005
PLAYBACK STYLUS TIP R .0025"
GROOVES CUT WITH 70° STYLUS (TIP RADIUS .0017")
PLAYBACK STYLUS TIP R .0025"
GROOVES CUT WITH 90° STYLUS (TIP RADIUS .0017")

Fig. 9-107. Theoretical stylus fit in grooves of various width. (Courtesy RCA.)

Since acetate-lacquer-coated blanks often contain a volatile softener which gradually evaporates, purchases should be limited to quantities suited to immediate needs. The blanks should be stored in metal containers sealed with tape. This will retard the evaporation of the softening agents and thus preserve the freshness of the cutting surface. Careful attention to the condition of the blanks will insure maximum groove quietness in the completed recordings.

The discs must be protected from dust and fingermarks before and after recording. The blanks, when received, may have a small amount of dust on the surface. Before starting to make a recording, wipe the disc surface with a wad of soft cotton, slightly moistened with water. Do not wipe the blank with dry cotton. (This will build up an electrostatic charge on the surface.) See that no water spots remain on the record surface. It is a good practice for the operator to wear thin fabric gloves when handling records. Dust and fingermarks cause a rapid rise in surface noise. Records should be kept in their envelopes when not in use.

The following table is included as a guide to the approximate maximum playing time for the various sizes of records:

Record Playing Time

Grooves Per Inch	Turntable Speed RPM	Approximate Playing Time (minutes)		
		16-inch Record	12-inch Record	10-inch Record
96	78	6½	4	2¾
112	78	7½	4½	3¼
120	78	8	5	3½
136	78	9	5½	3¾
154	78	10	6	4
96	33⅓	14	8	4¼
112	33⅓	16	9¼	6
120	33⅓	17	9¾	6
136	33⅓	18	10	6
154	33⅓	20	11	6½

Note · 17¼-inch blanks to be used for recording "masters" should be recorded as a 16-inch blank.

3. *Groove Spacing.* The correct groove width is determined largely by the radius of the tip of the playback stylus and by the signal level at which the recording is made. The groove should be wide enough so that the playback stylus tip contacts the side walls of the groove approximately 0.5 mil below the surface of the record. Then ordinary light surface scratches will not be reproduced and will not add to the overall record noise. Most lateral transcription pick-ups use styli which have tip radii between 2.3 and 2.5 mils. In order to obtain the proper fit, a groove width of 4.5 mils or greater is recommended for cutting styli having either a 70° or 90° included angle. Figure 9-107 illustrates the theoretical fit for various sizes of playback styli and groove widths. The tip radius of the cutting stylus should be 0.4 or 0.5 mils less than that of the playback stylus so that the bottom of the record groove is cleared and does not form the major support for the reproducing tip.

To determine the pitch (number of grooves per inch) at which the record is to be cut, add to the groove width twice the maximum amplitude of expected stylus excursion (due to signal) plus an allowance for safety factor. Assume a normal stylus excursion of 0.626 mils and a maximum of

10 db above this or 1.98 mils. Twice this is 3.96 mils plus a safety factor of 1.0 mil added to a groove width of 4.5 mils equals 9.46 mils, or about 109 grooves per inch. Low-frequency peak amplitudes of 10 db above normal are infrequent and it is questionable if two maximum stylus excursions will occur in adjacent grooves at such time and phase as to cut into each other. Therefore, some liberty can be taken and a slightly smaller pitch, about 7.35 mils, or 136 grooves per inch, is usually considered satisfactory when using a 70° cutting stylus.

Note: The groove width should never be less than 4.5 mils when a playback stylus with a 2.3 to 2.5 mil tip radius is used.

The tabulation below shows the practical limits of groove and wall widths. All dimensions are in inches.

Groove Dimensions

Grooves Per Inch	Combined Width of Groove and Wall	Groove Width		Wall Width		Groove Depth			
						70° Stylus		90° Stylus	
		From	To	From	To	From	To	From	To
96	0.0104	0.0052	0.0042	0.0052	0.0062	0.0022	0.0015	0.0018	0.0013
112	.0089	.0044	.0036	.0044	.0053	.0017	.0011	.0014	.0010
120	.0083	.0041	.0034	.0041	.0049	.0014	0.0009	0.0012	0.0009
136	.0073	.0036	.0029	.0036	.0044	.0011		.0010	
154	0.0065	0.0032	0.0026	0.0032	0.0039	0.0008		0.0008	

4. *Level Indication.* In the recording set-ups illustrated in Figure 9–106 a standard VU meter is shown connected across the output terminals of the recording amplifier. This is usually the most convenient method of indicating the recording level. Under these conditions (with the meter operating across a 15-ohm line instead of across a 600-ohm line) the meter reading is not the true power level of the line. The following table is included for reference:

STANDARD VU METER CONNECTED ACROSS A 15 OHM LINE

Meter Reading	Actual Line Level	Power in Watts
+ 4	+20	0.1
6	22	0.159
8	24	0.251
10	26	0.398
12	28	0.631
14	30	1.000
16	32	1.585
18	34	2.55
20	36	4.00
22	38	6.32
24	40	10.00
26	42	15.85
28	44	25.55
30	46	40.00
32	48	63.20
34	50	100.00

5. *Measurement of Peaks.* It should be understood that the standard VU meter indicates the average program level of the recording channel and does not show the actual height of the peaks which occur. These peaks may run approximately 10 db higher than the reading of the VU meter.

In order to guard against amplifier overload or overcutting of the recorded grooves, some form of peak-reading device such as a cathode-ray oscillograph should be used as a frequent check on recording levels. Reference lines can be marked on the face of the cathode-ray tube to indicate maximum allowable levels.

6. *Recording Levels.* It is assumed that the user is somewhat familiar with the operating fundamentals of instantaneous recording. If not, some experience and skill will need to be acquired before the finest results can be obtained. It is impractical to make an exact statement of the correct operating level for any recording set-up Although the sensitivity of the MI–11850–C recording head does not vary more than 2 db, the correct level can be established only by experience and test. There are no fixed boundaries in disc recording representing 100-percent modulation. At low frequencies the groove spacing limits the possible amplitude of the cutter. At high frequencies the radius of turning of the groove is the limiting factor.

It is not difficult to find the correct operating levels for a complete installation if test cuts of speech and music are made at the standard record speeds, using the smallest contemplated groove diameters. These test cuts should be made at gradually increasing levels, and the results should be noted when the records are reproduced. When the reproduction ceases to be acceptable from a quality standpoint, the maximum level has been exceeded. The presence of a very small amount of distortion is sometimes less objectionable than excessive surface noise, which is one reason, from a practical commercial standpoint, for not being guided too strictly by measured distortion.

It is well to keep in mind what type of equipment will be used to reproduce the recorded material. Only the most advanced type of pick-up, equipped with a diamond or sapphire stylus, should be used if the best quality of reproduction with low noise level is desired.

As a guide to determining the proper recording level, but without attempting to establish any fixed limits, it is suggested that the gain of the recording channel be set so that the VU meter, shown in Figure 9-106, indicates + 13 vu. A test recording of music can then be made. The result when reproduced will assist in determining the correct level for the particular type of program material it is desired to record.

Transcription records for 33⅓ rpm cannot be cut at as high a level as records for 78 rpm, because of the reduced surface velocity of the record material. It is usually necessary to hold the recording level down at least 6 db on the 33⅓ rpm discs. A higher level is usually used for 33⅓ rpm lacquer master discs for processing than for recordings where the original is to be played back repeatedly. A high-level, soft-lacquer original will not withstand repeated playbacks. However, the surface noise of the direct-cut disc is low so that there is no need for the maximum level.

It is obvious that in a busy transcription department a variety of recording levels cannot be maintained, so that a compromise level is the usual result. This means that the maximum quality cannot be reached with all types of recording, since most commercial transcriptions are cut at a high level.

7. *Duplicating Transcriptions.* When attempting to duplicate on lacquer discs the volume level found on commercial pressed transcriptions, the same precautions must be taken against over-cutting as were used when making the transcription. These include the careful control of cutting levels and the making of a simultaneous duplicate recording at a lower level to be used in the event that the louder recording is over-cut. The practice of recording important programs on a single machine indicates unjustifiable optimism. The loss of a single program could cost as much as an additional machine. One man can easily operate duplicate recorders.

8. *High Frequency Losses.* All disc recordings suffer from loss of high-frequency response during playback, in the area nearer the center of the disc. As the diameter of the recorded grooves becomes smaller, the condition becomes progressively worse because of the reduction in the linear speed of the recorded groove. With the slower groove speed, the actual linear distance available for a complete cycle of, for example, a 10,000-cycle tone, becomes very short. The cutting stylus has a front face which is a flat plane, and can record the high frequencies at the slower groove speed without difficulty. The limiting factor becomes apparent when an attempt is made to reproduce this recording. The reproducing stylus must of necessity have a tip of spherical shape. It is obvious that this tip cannot follow a recorded groove whose radius of turning is less than the radius of the stylus tip.

It is desirable to confine high-fidelity recording to large diameters, dividing the time on two or more discs, if necessary, for maximum quality. Records having extended frequency range cannot be made at a diameter of less than 9 inches for 33⅓ rpm without extreme loss of high-frequency response.

9. *High-Fidelity Records.* In making high-fidelity records, including discs for immediate playback, use can be made of what is known as complementary compensation. Because of the energy distribution in most speech and music, it is possible to accentuate the higher frequencies when making a record and then to attenuate these frequencies by a like amount in reproduction, thereby reducing the surface noise resulting from minute foreign particles in the record stock.

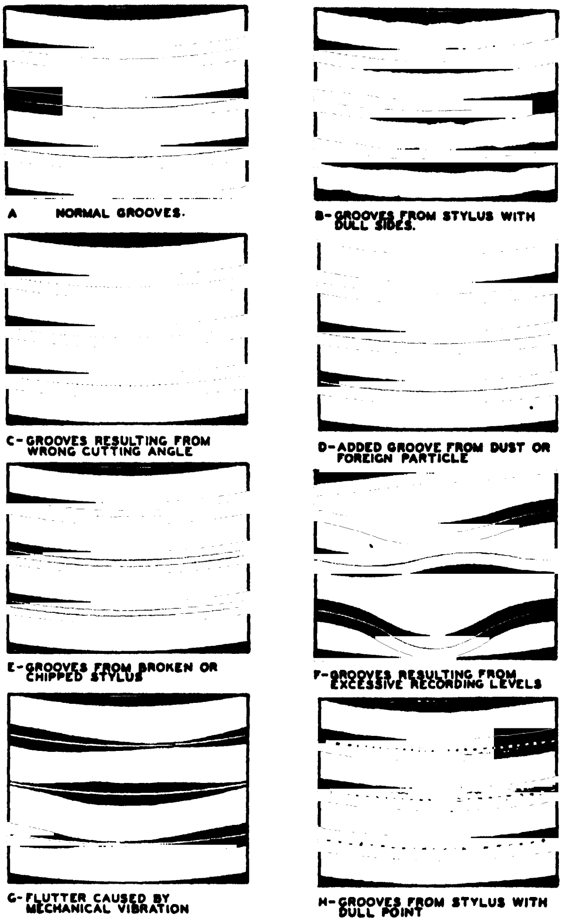
For high-quality recordings, the frequency rise should begin at about 700 cycles and should increase smoothly to a maximum of 16 db at 10,000 cycles. The RCA orthacoustic recording filter MI-4916 has been designed for this purpose. In reproduction, the inverse of this rise should be used. This attenuation is obtained at position number 1 of the filter switch on type 70-C2 turntables. Pre- and post-equalization, as this method of compensation is often called, results in a substantial reduction of surface noise.

Another form of high-frequency compensation involves the use of an automatically variable equalizer such as the MI-11100 or the MI-11101, developed for 33⅓ rpm recording. With this device the high-frequency compensation is progressively increased as the recording groove diameter becomes smaller. The equalizer mounts on the rear of the recorder mechanism, and is synchronized with the cutter head so that the amplifier gain is increased at the high frequencies to an amount which is considered a practical maximum.

10. *Flutter.* The term *flutter* is used to describe a vertical wave or oscillation which is sometimes cut in the recorded groove. This condition can often be seen as a series of radial "spokes" or patterns in the record surface. These patterns are usually visible before the record is reproduced, although sometimes they may be seen more plainly after playing. When viewed through a microscope this condition appears as an alternating change in width of the cut groove. See Figure 9-108.

Flutter may be caused by a building vibration, low-frequency turntable rumble, incorrect stylus angle or a blank having an unusually wavy surface.

11. *Hard Spots.* Hard spots in a blank will result in a condition similar to that caused by flutter. As the stylus passes over harder and softer portions of the surface, the cutter head is raised or lowered slightly, causing a variation in the depth of groove. This variation should not be mistaken for flutter or oscillation, since it is the normal action of a well-designed and free-acting recording head. A distinctive characteristic of hard spots is their preva-


A NORMAL GROOVES.

B-GROOVES FROM STYLUS WITH DULL SIDES.

C-GROOVES RESULTING FROM WRONG CUTTING ANGLE

D-ADDED GROOVE FROM DUST OR FOREIGN PARTICLE

E-GROOVES FROM BROKEN OR CHIPPED STYLUS

F-GROOVES RESULTING FROM EXCESSIVE RECORDING LEVELS

G-FLUTTER CAUSED BY MECHANICAL VIBRATION

H-GROOVES FROM STYLUS WITH DULL POINT

FIG. 9–108. Recorded groove characteristics. (Courtesy RCA.)

lence near the outside of the blank. Therefore, variations in groove depth due to hard spots will be more prevalent in this region.

12. *Adjustments.* It is very important that the feed-screw mechanism be adjusted so that the carriage supporting the recording head travels in a plane exactly parallel to the surface of the turntable, in order that the depth of cut will be uniform over the entire record surface.

The front face of the stylus, when in cutting position, should be adjusted to within plus or minus 3° of perpendicular. Some experiments may be necessary to find the most satisfactory angle for any given surface material. Refer to Figure 9–109.

It is advisable not to stop the turntable with the recording head in the cutting position, since the stylus may cut through the acetate coating to the metal core of the blank. This will chip the cutting edge of the stylus when the turntable is moved or the head raised.

13. *Stylus Noise Tests.* It is good practice to make surface-noise tests from time to time with all of the cutting styli available. This will assist the operator in selecting only those cutters which produce clean, quiet grooves.

Present standards require the noise level on lacquer records to be down 50 db from normal recording level. When checking noise, it is necessary to refer the noise level to some standard level. It is suggested that the 1000-cycle tone band of a standard tone record be selected as a reference level.

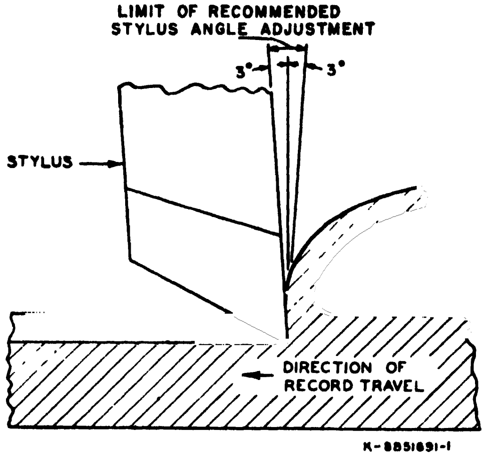

LIMIT OF RECOMMENDED STYLUS ANGLE ADJUSTMENT
3°
3°
STYLUS
DIRECTION OF RECORD TRAVEL
K-8851891-1

FIG. 9–109. Stylus-angle adjustment.

To determine the noise level, connect a high-fidelity pick-up through a calibrated attenuator to the input circuit of a high-gain amplifier. Insert a high-pass filter in the circuit to eliminate all frequencies below approximately 200 cycles. The electrical location of the high-pass filter is important. If two amplifiers are used, connected in cascade, the ideal electrical location for the filter is between the amplifiers. Should it be necessary to use a single-unit amplifier, the filter may be connected between the pick-up and the amplifier input. Be sure to provide adequate shielding for the filter when using it in this position, however, since the hum pick-up may be severe. Connect the amplifier output to a loudspeaker and a volume-level-indicating meter. Play the 1000-cycle tone band and then the noise sample. Adjust the output of the amplifier with the calibrated attenuator until a similar indication is obtained on the volume-level-indicating meter. The attenuator reading indicates directly the noise level in db below reference level.

A convenient method of determining the presence of noise or scratch consists of connecting the cutter head as a reproducer. Insert the stylus to be checked in the cutter head and connect the leads from the head directly to the input terminals of a high-gain amplifier which has a loud-speaker connected to its output terminals. Cut grooves in the record material, preferably near the outside diameter. Raise the gain of the amplifier sufficiently to hear the sound made by the cutter. A steady hiss indicates a good grade of lacquer and a sharp, properly adjusted stylus. Scratching, squealing, or tearing sounds indicate a dull or improperly adjusted stylus. Clicking or banging may indicate foreign particles in the lacquer.

If a 30 × to 50 × power microscope is available, the recorded grooves may be inspected and the quality of the recording determined very accurately. Adjust the microscope so that it is tilted about 15° from the vertical, and arrange a small illuminating source so that the incident light will be reflected from the record into the lens of the microscope. A quiet groove will appear as two sharply defined heavy black lines with a brilliant, narrow white line between them. Refer to Figure 9–108, which shows normal grooves and various defective groove conditions that may be observed.

9–59f. Advance-Ball Mechanism—The MI–11851 advance ball attachment has been especially designed for use with the MI–11850–C high-fidelity recording head and is available in kit form.

The advance ball is a sapphire cylinder, with a highly polished spherical tip, mounted in a duralumin shank.

The purpose of the device is to control the depth of the recording groove accurately. The ball rides on the uncut portion of the record surface, supporting the cutter head at a constant height above the record, so that the depth and the width of the groove will remain constant. A knurled adjusting knob on top of the cutter head adjusts the vertical position of the ball to regulate the depth of the cut. Provision is made for moving the advance ball to a position on either side of the cutting stylus to accommodate either outside-in or inside-out recording as may be desired.

Most operators consider the advance-ball attachment essential when recording on wax. Many also prefer to use this device when recording on lacquer.

9–60. Broadcast Studio Sound Reinforcement—In large broadcasting studios and radio theaters, where a studio audience is present during the presentation of radio programs, it is usually essential to provide sound reinforcement (PA) facilities to enable the studio audience to hear all portions of the program in proper perspective. If these facilities are not provided, the undesirable situation often arises where the studio audience is unable to hear parts of the program. In some types of programs, such as an audience participation show, this may result in an otherwise outstanding performance falling "flat."

In addition to reinforcing sounds originating on the stage of the broadcast studio, the sound reinforcement system also serves other purposes. For example, by means of the sound reinforcing equipment, the studio audience is enabled to hear those portions of a program which may originate from a remote point. Another use of the sound reinforcement equipment is in achieving special effects, such as the illusion of added room reverberation, or the creation of echo effects. Each of these functions of the equipment must be kept in mind in designing a studio sound reinforcement system.

9–60a. Design Considerations—A simple (but ineffective) method of obtaining the program feed for sound reinforcement is to bridge the sound reinforcement amplifier, or amplifiers, across the outgoing studio program line. When this is done, the program material reproduced on the sound system is exactly the same as that leaving on the outgoing line. Such an arrangement, while workable, leaves much to be desired as all portions of the program are, in this case, reinforced equally. More effective sound reinforcement is obtained, on the other hand, when only those portions of the program which could not otherwise be easily heard are reproduced on the studio loud-speakers. As an example, an orchestra, which can be heard without difficulty in all parts of the studio need not be reinforced and to do so would result in a jumbled, confusing performance reaching the studio listeners. However, the voice of a featured singer performing with the orchestra should be reinforced to be easily heard in all parts of the studio.

From the above discussion it can be seen that satisfactory sound reinforcement requires a different mixing technique than that employed in mixing program material for the usual broadcast purpose. This is often accomplished by employing a separate mixing console and operator for the specific purpose of preparing the program material for sound reinforcement and properly controlling the over-all loud-speaker levels during the performance.

9–60b. Methods Employed—It is obvious that it is not practical or desirable to employ separate microphones in the studio for sound reinforcement purposes. It is therefore necessary to design the audio system in such a manner that the output voltage from each of the studio microphones is available at both the regular mixer and sound reinforcement mixer. A method of accomplishing this, which has been in use by CBS for some time, makes use of a bridging transformer connected across the output of each of the microphone preliminary amplifiers (i.e., ahead of the regular mixer controls), Figure 9–110. The outputs of these transformers provide the program feeds to the sound reinforcement mixer.

In addition to supplying program feeds to the sound reinforcement mixer from each microphone channel, similar feeds should be provided from all other sources of program material. For example, if program material is obtained from transcription turntables or from incoming program loops, feeds to the sound reinforcement mixer should be arranged from these sources of program material. It is by means of the program feeds from incoming program loops that reproduction of program material from remote points is made possible.

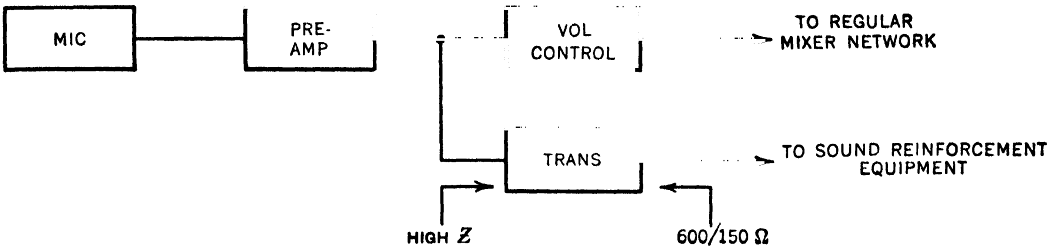


FIG. 9–110. Program feeds from the studio console to an external sound reinforcement mixer may be obtained by means of a bridging transformer or bridging pad connected across the output of the microphone preliminary amplifier as shown above. If bridging pads are used several precautions must be observed as discussed in the text. (Courtesy CBS.)

Bridging pads may be used instead of bridging transformers, and they will accomplish comparable results at lower cost; however, because of the greater attenuation in the bridging pad, care must be taken that the signal level through the sound mixing system does not fall below the original microphone level if the greatest possible signal-to-noise ratio is desired. Another precaution to be observed when bridging pads are employed is the circuit grounding arrangement. If circuit grounds are made at more than one point in the system, difficulty with ground currents and resultant hum and cross-talk may be encountered.

It would not be economically justifiable to include a sound reinforcement mixer position for each of the program feeds, inasmuch as upwards of ten such feeds may be involved. An inexpensive and entirely satisfactory method of simplifying these mixing facilities is through the use of a smaller mixer panel, four positions usually being adequate for average installations; each individual mixer control receiving program material from a suitable selector such as a rotary switch or mechanically interlocked push button with the required number of positions as in Figure 9–111. In this way any of the program feeds may be connected to any desired mixer position.

The most suitable location for the sound reinforcement mixing console must also be given careful consideration. One possible location is in the control room immediately adjacent to the regular mixing console. This arrangement has been used in the past and has the advantage that all equipment is centralized in the control room and long low-level audio cable runs are not required. Such an arrangement has one very serious disadvantage; that is, the operator must depend on the studio loudspeaker level adjustments made before the program commences and has no way of knowing (with the possible exception of hand signals from an assistant

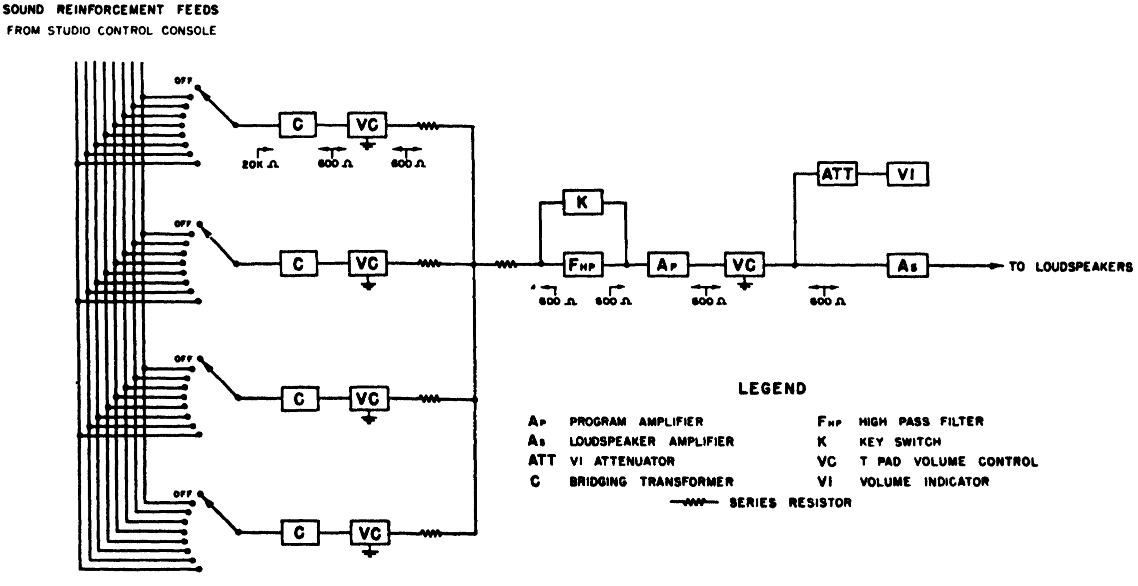


FIG. 9–111. A simplified block diagram of the circuit arrangement of the sound reinforcement mixing console. Four mixer positions, which may be bridged across any one of the eight program feeds, are provided. The fact that the bridging transformers are incorporated in the sound reinforcement channels instead of the incoming program feeds results in a saving of transformers. (Courtesy CBS.)

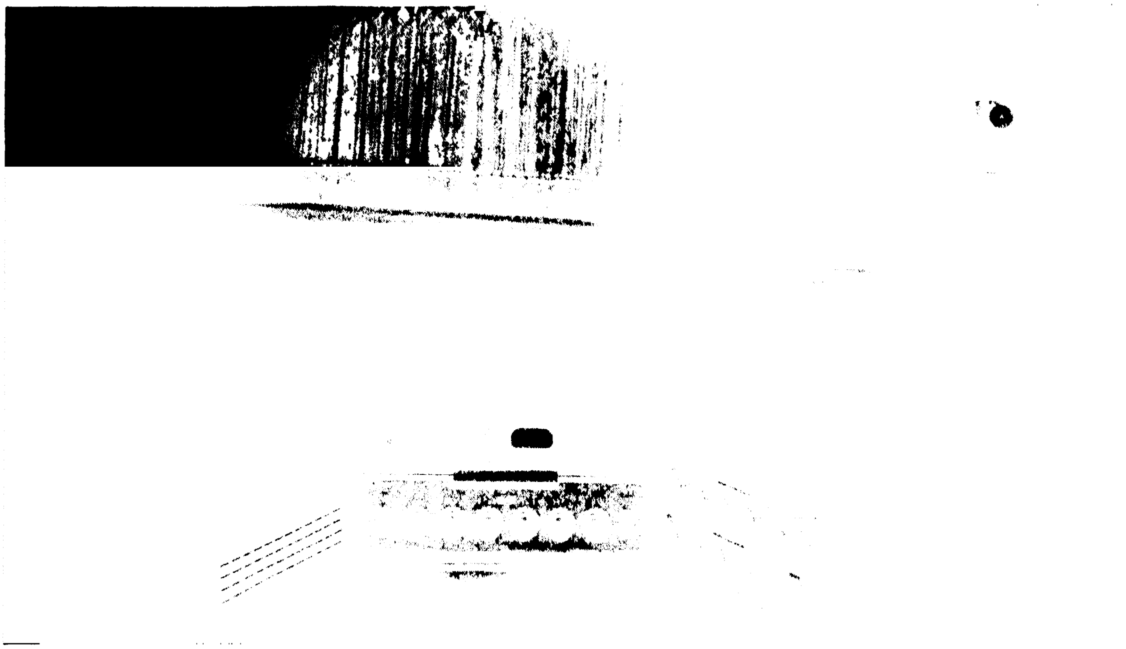


FIG. 9–112. A photograph of a sound reinforcement control console installed in the audience area of a CBS radio theater. Such a vantage point is highly desirable for this activity as the operator has first-hand knowledge of the degree of reinforcement required and the effectiveness of all operating adjustments. (Courtesy CBS.)

in the audience) if the studio levels are satisfactory after the program gets under way. In view of this, it is generally desirable, despite the additional cable runs involved, that the sound reinforcement mixing console be installed in the audience section of the studio, where the operator will have first-hand knowledge of the degree of reinforcement required and the immediate result of all operating adjustments, Figure 9–112. When this is done, suitable communication (telephone or signal lights) should be provided between the sound reinforcement mixer and the control room to permit the control room to notify the sound reinforcement operator if the loud-speaker levels are interfering with the air program.

There is another method of controlling sound reinforcement which, although exhibiting one of the shortcomings already noted, has the advantage of extreme simplicity. In this method an additional operator is not required as the few controls involved may be mounted on the regular mixer panel and handled by the control room operator.

In this method, sound reinforcement feeds are obtained from each channel by means of a suitable bridging device. In this case, however, the bridging device is connected across the *output* of the regular mixer controls. The sound reinforcement feed thereby obtained then passes through a suitable "on-off" switch after which all feeds are combined by means of a mixer matching network. The output of the network connects to the sound reinforcement amplifier in the usual manner.

Operation of such a system is extremely simple. The operator simply selects the channels to be reinforced by means of the individual channel "on-off" switches. The level of each channel is, of course, a function of the adjustments being made on the regular mixer control inasmuch as the sound reinforcement feed is obtained at the *output* of this control. The only other control involved is a sound reinforcement master volume control which may be set prior to going on the air.

The disadvantage of this method lies in the fact that the operator, being in the control room, has no way of knowing the effectiveness of the sound reinforcement coverage after the program gets under way. Furthermore, the balance between the program elements being fed to the sound reinforcement system is determined entirely by the requirements of the air show. This will not necessarily be the optimum balance for the sound reinforcement service.

9–60c. Loud-speaker Placement—The loud-speaker placement practices followed in motion picture theater sound systems and theater public address work cannot be employed in broadcast studio sound reinforcement because the microphones are often set up in the audience section of the studio. In some radio theater pick-ups, the main orchestra microphone is suspended as far back as the forward edge of the first balcony. For this reason, no general rules can be set down concerning the number of loud-speakers to be employed or their placement, as each particular installation presents specific problems.

In general, there are two different approaches to the problem of loud-speaker placement. The first makes use of a small number of loud-speaker units, usually two (but sometimes four) placed at each side of, and slightly forward of, the stage. This arrangement, because of its simplicity and effectiveness, is in wide use at the present time. The second approach to the loud-speaker placement problem makes use of a multiplicity of loud-speaker units which are uniformly distributed throughout the audience area. Each loud-speaker unit is operated at a relatively low level with the result that the auditorium is literally flooded with sound although the level is not objectionably high at any one point. This arrangement can be used to advantage in theaters where a mezzanine and several balconies make coverage with a small number of speaker units impractical.

9-60d. Acoustic Feedback—One of the more serious difficulties experienced in the operation of sound reinforcement systems is the tendency of the system to "sing" as a result of acoustic coupling between loud-speakers and microphones. This tendency to sing can be reduced by operating the loud-speakers at a reasonably low level, as it is not necessary to provide the studio audience with more than comfortable listening level. In addition to conservative operating levels, there are several design considerations by means of which it is possible to reduce the tendency of a sound reinforcement system to sing. These design considerations include:

1. Loud-speaker units with sharp peaks in their response-frequency characteristics should be avoided as the high peak output at these points is often sufficient to set the system into oscillation even if it is operating at a conservative level. Loud-speaker units with smooth response-frequency characteristics, usually associated with the more costly units, reduce the tendency of a sound system to sing.

2. Inasmuch as the greatest energy content of average voice and speech exists in the lower audio frequencies (below 400 cycles), the attenuation of these frequencies does much to reduce the tendency of the system to sing; furthermore, these frequencies may be attenuated without seriously reducing the intelligibility of reproduction. One method of reducing the low-frequency output consists of inserting a high-pass filter section in the system. A simple prototype filter section with a cutoff frequency in the range 250 to 400 cycles and an attenuation in the order of 12 db per octave or less is usually effective. This filter should be removed from the system when reproducing program material from a remote point as wide-band reproduction is then desirable.

The above discussion suggests a simple, but very effective, method of meeting the requirements of both (1) and (2) in a direct manner. This is by the use of dual loud-speaker units of the theater type which employ a multicellular high-frequency reproducer and a horn or direct radiator type low-frequency reproducer with a cross-over frequency in the order of 400 cycles. When employing the system for sound reinforcement purposes, the high-frequency unit only is used. This type of reproducer usually has reasonably smooth response-frequency characteristics above the cross-over frequency, thereby meeting the requirements of (1), and has the required attenuation below the cross-over frequency, thus meeting the requirements of (2). When the system is employed for sound reproduction of program material from a remote point and full frequency range reproduction is desired, it is simply necessary to use the complete dual reproducer system.

The use of the high-frequency reproducers alone reduces the susceptibility of the system to feedback in another manner. This results from the property of loud-speakers to radiate the higher frequencies with directional properties, usually in the form of a beam, the width of the beam being a function of the loud-speaker design and the frequency involved. These directional properties permit the loud-speakers to be located in such a manner that the microphones are protected from receiving appreciable direct pick-up from the loud-speaker units.

The problem of feedback may appear to be complicated by the presence of "audience reaction" microphones in the audience section of the studio. However, difficulty with feedback will not be encountered from this source, provided that no attempt is made to reinforce the output of these microphones. Another difficulty, commonly known as "slap-back," may be encountered when the audience reaction microphones are open. This is due to sound from the loud-speakers being picked up by the audience reaction microphones and appearing as an echo on the air channel. The only means of reducing "slap-back" is to protect the audience reaction microphones from the full field of the loud-speakers by careful placement of both microphones and loud-speakers.

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CHAPTER 10

STANDARD BROADCAST TRANSMITTERS

Standard broadcasting stations in the United States operate in a frequency band extending from 550 to 1600 kc. Frequency assignments are made throughout this band at intervals of 10 kc, resulting in a total of 106 available channels. There are three classes of broadcast channels: *clear channels,* for the use of high-powered stations, *regional channels,* for the use of medium-powered stations, and *local channels,* for the use of low-powered stations. Frequency assignments are made in a manner designed to result in a minimum of interference between stations occupying the same or adjacent channels. This is accomplished by making assignments of the same or adjacent channels in widely separated areas of the country, and in many cases requiring the use of directional antennas to reduce the power radiated by a station in the direction of another station with which interference would result. Many stations are licensed for daytime operation only to avoid nighttime interference with other stations because of sky-wave radiation.

10–1. Location of Broadcast Transmitters— Radio broadcast studios are usually centrally located in the city they serve, in order that they may be conveniently reached by artists and performers, as well as by studio audiences. The location of the broadcast transmitter, on the other hand, is influenced by many technical as well as economic considerations, some of which are listed below.

1. The transmitter must provide a satisfactory signal strength to the city being served and, in addition, provide the maximum possible coverage to other near-by populated areas. The present-day practice of employing indoor receiving antennas, built-in loop receiving antennas, or no receiving antenna at all requires that a relatively strong signal strength must be provided if reception is to be free from interference from local electrical disturbances. In the industrial and business areas of large cities, a field intensity ranging from 25 to 100 millivolts per meter is desirable; in residential areas, 2 to 5 millivolts per meter is usually sufficient, although a considerably stronger signal may be required in some particularly noisy areas; in rural areas, a field intensity of 0.5 millivolts per meter is generally adequate.

2. The population in the immediate vicinity of a large transmitter should be small. The very high field intensity may result in a signal so strong that it will interfere with reception from other stations. This usually precludes locating any but low-powered transmitters near the center of a city.

3. The soil conductivity at the transmitter location must be good. The signal strength from a transmitter in a location of poor soil conductivity may be only a small fraction of the signal strength obtainable from the same transmitter and radiating system in a location of good soil conductivity. The transmitter illustrated in Figure 10–1 is located on an island surrounded by salt water and is particularly effective.

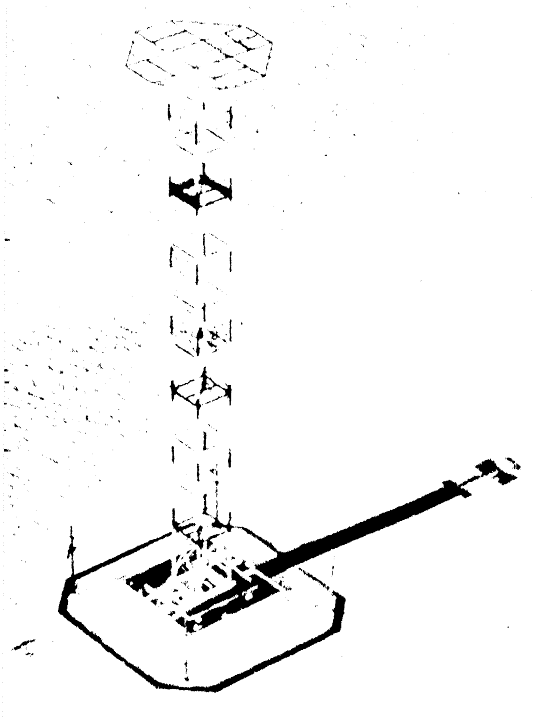

Fig. 10–1. A modern broadcast transmitter—WCBS, New York—located on an island in Long Island Sound. (Courtesy CBS.)

4. The transmitter must be in a location accessible to both power and telephone lines. Water supply should also be available. Roads leading to the transmitter should be passable at all times of the year.

Other considerations—cost of land, proximity of radio communication installations, proximity of airports and airways, and proximity of large metallic obstructions, such as gas tanks and large buildings—also influence the location of a broadcast transmitter. In addition, if a directional antenna is employed, it will usually dictate the direction from the city that the transmitter must be located.

The final site of a broadcast station is selected only after many measurements and calculations have been made to determine the performance to be expected from that location. Low-powered test transmitters are often set up at proposed sites and field strength measurements, corrected for differences in power and antenna efficiency, made to determine the performance to be expected of that site. At other times, when another station is already operating from a location near a proposed site, field strength measurements can be made of this station and then corrected for differences in frequency, power, and antenna efficiency.

The final location of most broadcast transmitters, with the exception of lower-powered stations, will usually be in thinly populated outlying areas of the city being served. Low-powered stations are usually located as closely as possible to the center of the city to produce a satisfactory signal to the areas containing the largest population.

10–2. The Transmitter Plant—A broadcast transmitting plant, in addition to a suitable transmitter and radiating system, should contain the following facilities.

1. Audio input equipment, including program line terminal equipment, amplifiers, and monitoring equipment. The use of a peak-limiting or automatic gain-adjusting amplifier is desirable to increase the average percentage of modulation.
2. Local origination facilities, whereby programs may be originated directly from the transmitting plant. Such facilities consist essentially of a microphone and transcription turntable, together with suitable amplifiers and control equipment.
3. A regular and emergency supply of a-c power.
4. Measuring equipment capable of measuring accurately the frequency, modulation percentage, antenna phasing (if a directional antenna is employed), and complete performance characteristics of the transmitter. A cathode-ray oscillograph is also quite useful.

A communications receiver for receiving standard frequency transmissions and time signals is also desirable. If possible, this unit should, in addition, cover the standard and F–M broadcast bands.

10–3. Program Lines and Primary Power Supply—Inasmuch as broadcast transmitters are usually located some distance from the studios, it is necessary to employ wire lines, usually leased from the local telephone company, to carry program material from the studios to the transmitter.

As continuity of service is essential in a well-operated broadcast plant, it is desirable that two program lines be available, the first for normal use, and the second for emergency use in the event that the regular line becomes noisy or fails completely. A further emergency measure, employed at many stations, is to equip the transmitter with the necessary facilities for originating programs directly from the transmitting plant in the event of the failure of all telephone facilities. This can be accomplished by means of a microphone and transcription turntable, which are usually adequate to maintain emergency program service until the wire line facilities have been restored.

Another desirable precaution in the interest of maintaining continuous service under emergency conditions is the availability of power from two different sources. Should power from one of the two sources fail, operation need not be suspended. The emergency power may be obtained by means of a separate line from a second sub-station, or may be obtained from a gasoline- or Diesel-operated generator installed in the transmitter plant.

10–4. Peak-limiting Amplifiers—Peak-limiting or automatic gain-adjusting amplifiers are employed at most broadcast transmitter plants. A peak-limiting amplifier automatically controls the amplitude of program peaks in such a manner that none of the peaks is permitted to exceed a predetermined maximum value, this value usually being that which results in 100-percent modulation of the transmitter. The gain of a peak-limiting amplifier is essentially constant for all program levels below the predetermined maximum value, but, when a program peak exceeds this value, the gain of the amplifier is very quickly reduced the correct amount to keep the peak from exceeding the value corresponding to 100-percent modulation. After the peak has subsided, the gain of the amplifier is automatically restored to normal at a relatively slow rate.

With the protection against overmodulation afforded by this amplifier, it is possible to increase the audio level into the transmitter by several decibels, resulting in a substantial increase in the average percentage of modulation. The increased transmitter effectiveness thereby obtained is usually as effective as, but much less expensive than, an increase in the power of the transmitter or an increase in the height of the transmitting antenna. In addition to permitting an increase in the average percentage of modulation, the peak-limiting amplifier also prevents the operation of overload devices in the transmitter circuits by large program peaks and protects the high-power sections of the transmitter from possible damage due to overload by a sustained high program level.

In order to perform satisfactorily its function of preventing any program peak from exceeding the desired maximum level, the gain-reducing action of the peak-limiting amplifier must take place at an exceedingly fast rate. This time of gain reduction is known as "attack" time. If the peak-limiting amplifier is to be effective in preventing the passage of peaks with a steep wavefront, such as are constantly encountered in program material, the attack time must be in the order of 0.1 milliseconds and under no circumstances greater than 0.25 milliseconds.

Another important characteristic of a peak-limiting amplifier is the time required for the gain to be restored to normal after a peak has passed. This time of gain restoration is known as "recovery" time. Recovery times in common use range from 0.1 second to 2.0 seconds. If a fast recovery rate, such as 0.1 second, is employed, there will be less loss of low-volume program passages that follow immediately after a high program peak; however, such a fast recovery time often results in a tendency for the amplifier gain to be affected by the individual cycles of low-frequency signal voltages, thereby resulting in serious waveform distortion. A slow recovery time, in the order of 2.0 seconds, results in more perfect filtering of the audio control voltages and eliminates the tendency of the amplifier gain to be affected by low audio frequencies. A slow recovery rate also results in less noticeable gain reduction action as the program is restored slowly and unobjectionably following a period of gain reduction. In practice, optimum recovery time is largely influenced by the character of the program material, but usually lies in the region between 0.2 and 2.0 seconds. One type of automatic gain-adjusting amplifier, described later, has a unique circuit arrangement wherein the recovery time is an automatic function of the type of program material causing the gain reduction.

The advantages of the peak-limiting amplifier are:

1. It permits increased average percentage of modulation of the transmitter without danger of overmodulation and eliminates adjacent channel interference due to overmodulation.
2. It protects the transmitter from possible overload or damage caused by a sustained high program level and prevents the operation of overload devices, such as circuit breakers, by large program peaks.

These advantages are not attained without an accompanying disadvantage which, in this case, is a decrease in signal-to-noise ratio. The noise referred to includes all objectionable sounds associated with the program material including hum, thermal agitation, needle scratch, studio room noise, lip noises, and the rustling of script paper. This decrease in signal-to-noise ratio is brought about because the dynamic range of the program material is being compressed, that is, the higher program peaks are reduced in amplitude by the limiting action, while the relative amplitude of lower level program passages, as well as noise, remain unchanged. Therefore, it can be seen that the ratio of program peaks to average noise has been altered.

Provided that peak-limiting is intelligently employed, and too much limiting is not attempted, this increase in noise will be of little consequence and will only be detectable on program material where a noticeable noise level already exists, as for example, old or worn phonograph recordings with high surface noise.

10-5. General Electric Type BA-5-A Limiting Amplifier—The G. E. type BA-5-A limiting amplifier is a peak-limiting amplifier designed to permit a very substantial increase in the average program level of broadcasting and recording systems without danger of any audio peak exceeding a predetermined maximum value. The initial development work on this amplifier was done by the Columbia Broadcasting System technical staff.

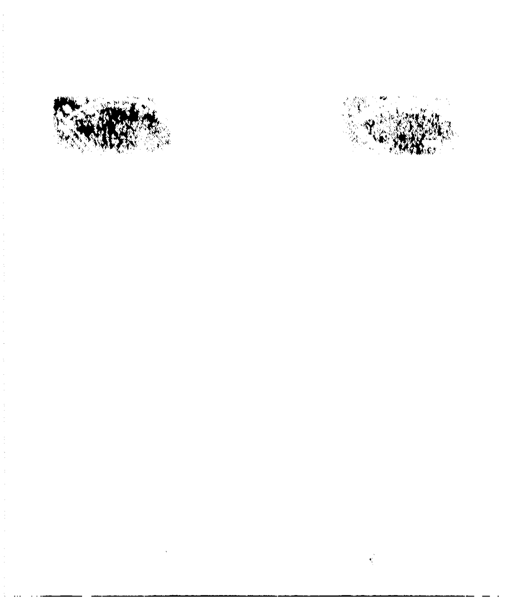

FIG. 10-2. The General Electric type BA-5-A limiting amplifier.

The G. E. BA-5-A limiting amplifier consists of two separate units designed for standard relay rack mounting. The amplifier unit requires 12¼ inches of rack mounting space, and the power supply unit occupies 10½ inches of rack space. The two units may be separated physically from one another as far as desired. Each unit employs vertical-chassis construction, with hinged front cover panels which swing open 90°, exposing the interior of the chassis. These provide easy access to all components when making periodic adjustments or when servicing the units in the rack. All controls and meters which are used in normal operation of the amplifier are mounted directly on the hinged panels, and do not need to be removed or disturbed in any way when adjusting or servicing the units in the rack. Several controls which are used only occasionally during adjustments of the amplifier are mounted on a sub-panel in the amplifier unit, and are exposed when needed by opening a separate, hinged cover panel.

A d-c meter is provided on the front panel of the amplifier unit for (1) indicating the degree of automatic-gain reduction directly in db, (2) indicating the balance of various tubes, (3) measurement of tube plate currents, and (4) measurement of plate voltage. A panel-mounted rotary switch selects the desired meter function.

The power supply unit contains two separate regulated power supplies, which provide potentials of 250 volts positive and 250 volts negative, respectively. These power supplies maintain constant d-c output voltages over a wide range of a-c line voltage variations. The front cover panel of the power supply unit mounts a power switch and a red-jeweled pilot lamp. Adjustment of the d-c voltage of the power supplies is accomplished by two controls mounted on a sub-panel in the interior of the power supply chassis. This sub-panel also mounts a 5-amp power fuse. The voltage-controls and fuse are readily accessible from the front of the unit by opening the hinged front cover panel.

10–5a. Specifications

Source impedance: 600 or 150 ohms, balanced or unbalanced.

Input impedance: 600 or 150 ohms, approximately, balanced or unbalanced.

Load impedance: 600 ohms, unbalanced.

Output impedance: 600 ohms, approximately, if at least 6-db attenuation is set up in adjustable output pad.

Input level: Maximum (at verge of automatic gain-reduction): − 2 dbm

Maximum (with 12 db gain-reduction): + 10 dbm

Minimum (at verge of automatic gain-reduction): − 33 dbm

Adjustable in 1-db steps between above limits by means of panel-mounted, 30-step, input level control.

Output level: Normal (at verge of automatic gain-reduction, and with zero loss in output pad) + 12 dbm. Adjustable in 0.2-db steps by a panel-mounted 45 step, output level control. Also adjustable in 1-db steps to any value between + 12 dbm and − 28 dbm by means of soldered taps on output T pad.

Level indicator: A panel-mounted VU meter and associated multiplier attenuator may be switched across the output of either the control amplifier stages or the pre-amplifier stages, permitting monitoring of program levels, either before or after the point where gain-reduction takes place.

Frequency response: ± 1 db, 30 to 15,000 cycles under any condition of gain reduction.

Gain (with maximum input-level-control setting, zero loss in output pad, and normal setting of output level control): 44 db.

Noise level (below output signal level at verge of gain reduction): − 70 db, max.

Steady-state distortion: Less than 1% total rms distortion from 50 to 15,000 cps for all values of automatic gain reduction up to 12 db.

Attack time: Less than 150 microseconds.

Recovery time: Automatic function of nature of program material.

For single, short peaks: 0.2 to 0.4 seconds, adjustable for 63% recovery of gain after signal drops below gain-reducing level.

For sustained or rapidly recurring peaks: Approximately the same as for single, short peaks up to about 40% gain-recovery, increasing automatically to about 7 seconds for 90% gain-recovery.

10–5b. Theory of Operation

1. *General.* This new type of automatic gain adjusting amplifier is composed of three sections. Tubes V11, V12 and their associated circuits compose the preamplifier section. Tubes V13, V14, V15, V16, V17, V18 and their associated circuits compose the variable-gain or controlled amplifier section. Tubes V19, V20, V21, V22, V23, V24 and their associated circuits compose the bias generator section.

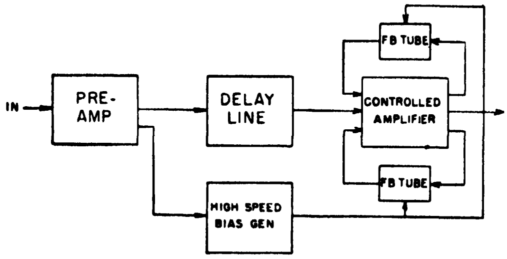

FIG. 10–3. Block diagram of the General Electric BA-5-A limiting amplifier.

The purpose of the preamplifier is to amplify the input signal to such a level that it can supply both the controlled amplifier and the bias generator sections.

In the controlled amplifier, tubes V13, V14, V17, V18 form a conventional two-stage, push-pull amplifier. Tubes V15, V16 are so connected that they apply negative feedback from the plates of the output stage to the cathodes of the input stage. The plate-to-cathode impedances of V15 and V16 determine the amount of negative feedback. This impedance changes with control grid voltage. It therefore comprises a variable gain amplifier.

It is desirable to obtain adequate control bias to cause gain-reduction even with peaks of very short duration. Therefore, the control-bias generating circuits utilize large power-type tubes and low-impedance circuits, resulting in extremely fast development of the automatic control voltage. Tube V19 is a phase inverter to supply signal to the push-pull cathode followers V20 and V21. Tubes V20, V21 provide a suitable low impedance charging source for the diodes V22, V23. Full-wave rectification in diodes V22, V23 produces the required d-c bias potential across their *R–C* load circuit.

Tube V24 is a dual triode. The first triode section of V24 serves the dual purpose of an inverter to obtain voltage of the correct polarity to bias the feedback tubes and as an equalizer tube. The function of the equalizer tube is to suitably shape the control-bias pulse applied to the feedback tubes. The second triode section of V24 serves the purpose of indicating the degree of gain-reduction on a calibrated meter.

The voltage change in the plate circuit of V24, which is in a positive direction, is applied to the grids of the feedback tubes V15, V16, which thereby reduces the gain of the controlled amplifier. Diodes V22 and V23 are biased so that gain reduction occurs at a predetermined input amplitude.

The audio signal voltage at the output of the preamplifier section feeds the control amplifier section through the lattice network composed of L11-A, L11-B, C19, and C20. This network acts to delay the signal voltage reaching the control amplifier until sufficient gain reduction has been effected by the bias generator circuits.

In order to minimize variations of the operating characteristics of the automatic gain adjusting amplifier due to line voltage variations, the plate supply voltages are regulated.

2. *Automatic Gain-Adjusting Characteristic.* The bias generator gets its signal from the input side of the controlled amplifier section. This bias generator must be designed to have, without external control, a certain a-c input vs. d-c output transmission characteristic. Up to the point of gain reduction, the output of the bias generator is zero. This zero-transmission is accomplished by applying fixed bias to the diodes V22 and V23.

Through the gain-reducing range, the bias generator transmission characteristic is controlled by the "slope" control R90. It is the combined effect of the bias generator transmission characteristic just described, plus the transmission characteristic of the controlled amplifier section, which constitutes the overall automatic gain-adjustment characteristic of the system.

3. *Tube Balance in Controlled Amp.* When gain reduction occurs, the plate currents of V15 and V16 change. Since V13 and V15 have a common cathode resistor, R32, and V14 and V16 also have a common cathode resistor, R33, the above change of plate currents will change the bias of the V13–V14 push-pull stage. V13–14 amplification of this bias-voltage change appears on the grids of the V17–V18 push-pull stage. Since this voltage appears in-phase, however, resultant currents in the primary of the output transformer T14 produce no energy in the secondary of T14, because the primary offers a zero impedance to in-phase currents, providing they are perfectly balanced. These in-phase voltages that appear on the grids of the V17–V18 push-pull stage when compression occurs, appear as a bias shift to these tubes. The duration of this bias shift is determined by the combined *R–C* coupling circuits and the gain reduction recovery time. The effects which would normally be expected from this bias change are minimized by the de-generative effects caused by R51. The large value of R51 is compensated for by the application of a bias voltage, which is positive with respect to ground, to the grids of V17, V18.

It is obvious, therefore, that in order to obtain proper performance, each pair of tubes in this push-pull gain-reducing section should be reasonably well balanced. This is especially true of V15 and V16 because they operate over the greatest portion of their grid-voltage plate-current curve.

4. *Recovery Time.* The time required for the amplifier to restore itself to normal gain from a reduced gain condition is called the recovery time. The *R-C* load circuit of diodes V22–V23 determines the recovery time. The design of this circuit makes the recovery time dependent on the nature of the signal which caused gain reduction, and for this reason it is difficult to describe simply the recovery time characteristic. The following description should, however, give some indication of what might be expected from this circuit.

The basic *R–C* load circuit for diodes V22–V23 is composed of R84, R86, R87 shunted by C34. Increasing of the recovery time is accomplished by rotating recovery switch (S11), which adds C35 or both C35 and C36 to the above *R–C* load circuit. This basic circuit then provides a recovery time of 0.2, 0.3 or 0.4 second for 63 percent gain-recovery. An additional anti-pump circuit composed of R88 and C33 in series, connected across the basic circuit, causes it to operate in the following manner: A high peak of short duration which causes compression will not charge the anti-pump circuit because of its slow charge characteristic: approximately 1.2 seconds. However, this peak will charge the basic circuit, and therefore causes gain reduction. Gain recovery for this condition will be very rapid since the bias voltage will start charging the anti-pump circuit while it is discharging through its regular leak circuit.

Now, if several high peaks of short duration occur during a short interval, causing gain reduction, the anti-pump circuit as well as the basic circuit will become charged, causing gain reduction. The gain recovery for this condition will be nearly as rapid as the condition stated above, up to about 40 percent gain-recovery. At this time, recovery rate will slow down, and when the ratio of the potential on C34 to that on C33 is equal to the ratio of R84 plus R86 plus R87 to R84 plus R86 plus R87 plus R88, recovery time will be determined by the C33, R88, R84, R86, R87 combination, and a total of about 7 seconds will be required for 90 percent gain-recovery. It can now be seen that when short peaks occur in rapid succession, causing gain reduction, the anti-pump circuit will take hold and limit the amount of recovery between peaks, thereby reducing the pumping effect. In the event of a sustained peak of high amplitude which causes gain reduction, both the anti-pump circuit and the basic circuit will charge, and the recovery time will be similar to that for the condition just mentioned. The advantage of the lengthened recovery time for this condition is that less dynamic range will be lost. From the foregoing, it will be evident that gain reduction will be less apparent to the listener than might otherwise have been expected.

5. *Bias Rectifier.* Signal input voltage to the bias generator and diode biasing determine what the preamplifier output level will be when the input level is such that the amplifier is on the verge of compression. R24 and R26 form a voltage-divider to deliver the proper input signal voltage to the bias generator with reference to the preamplifier output level. The bias applied to the diodes V22–V23 is an important factor in determining what the output level of the preamplifier will be when on the verge of compression. This bias also serves the purpose of preventing diode current without signal.

It is desirable that the d-c output voltages from diodes V22–V23 be proportional to the peak potential of the applied signal voltage. This is accomplished by providing a high signal voltage to the diodes, thereby increasing their linearity. But since a considerably smaller voltage is required by the inverter-equalizer (V24) grid, a voltage divider composed of R84, R86, and R87 is provided. C31 and C32 limit the impedance of the inverter grid at high frequencies, and thus restrict its pick-up of extraneous noise.

6. *Preamplifier.* The preamplifier is operated at an output level such that its signal-to-noise ratio at the verge of gain-reduction is satisfactory. Its output at this point is approximately + 10 dbm but this figure will vary somewhat, depending on tube characteristics (principally V15, V16 and V24).

The preamplifier is capable of delivering powers in the order of + 24 dbm with very low distortion. Thus signals within the full range from the verge of gain reduction to full gain reduction will be assured satisfactory transmission characteristics in the preamplifier.

10–5c. Alignment Adjustments and Maintenance

1. *General.* The necessity for proper alignment of this automatic gain-adjusting amplifier cannot be overemphasized. Regular and frequent checks on the proper alignment will be repaid by superior performance.

Whenever maintenance work is done inside the chassis, the DC MTR switch (S12) should be turned to the OFF position to prevent accidental damage to this sensitive instrument.

The following adjustments should be made upon initial installation and at regular maintenance intervals thereafter.

2. *Adjustment of Power Supply.* Place all the tubes in the amplifier and power supply units in their sockets except V15 and V16, and turn the equipment on. After several minutes of warm-up, turn the DC MTR switch S12 to the "+ PWR" position and adjust the + OUTPUT VOLTAGE control (R218) back of the hinged panel in the power supply so that M12 reads at PWR position (250V). Turn S12 to the — PWR position and adjust the — OUTPUT VOLTAGE control (R236) on the power supply so that M12 reads at the PWR position.

3. *Tube Check and Static Balance of Push-Pull Stages.* V11 and V12 operating currents are satisfactory if M12 reads within the green CHECK area in positions 1 and 2 respectively of S12. S12 should be rotated to positions 3 and 4 for an approximate check on the operation of V13 and V14 respectively. Indications should be within the green area. S12 should now be rotated to BAL A or BAL B position (whichever reads upwards). These positions indicate the relative unbalance of V13 and V14. If the reading is greater than 2 microamperes, other combinations of tubes should be tried until the proper balance is obtained. V15 and V16, which are not yet plugged into their sockets, will be checked for proper operation during and after the adjustment of automatic gain-reducing characteristic which is described in a subsequent section. Continuing the tube check, S12 should be rotated to positions 5 and 6 for checks on V17 and V18 respectively. These tubes should be selected so that their readings not only fall within the CHECK area, but differ by less than 3 microamperes.

V19, V20, and V21 should fall within the tube check areas on S12 positions 7, 8, and 9 respectively.

Other tubes in the amplifier must be tested by other means such as a standard tube tester.

4. *Adjustment of Gain-Reduction Indicator.* With the metering switch on the G-R position, adjust the G-R ZERO control (R93) until M12 reads full scale with no signal input applied to the amplifier. M12 will then read the approximate amount of gain-reduction when subsequent adjustments have been properly completed.

5. *Adjustment of Automatic Gain-Reducing Characteristic.* When making the initial adjustment of the automatic gain-reducing characteristic, begin with FB BAL (R43) and SLOPE (R90) (located behind the upper hinged section of the front panel) adjusted to the center of their scales. When tubes are replaced, or when making routine check adjustments begin with the FB BAL and SLOPE controls in the position found optimum at the last previous adjustment.

Put V15 and V16 in their sockets and allow approximately one minute of warm-up before starting adjustments. Make certain that the output ter-

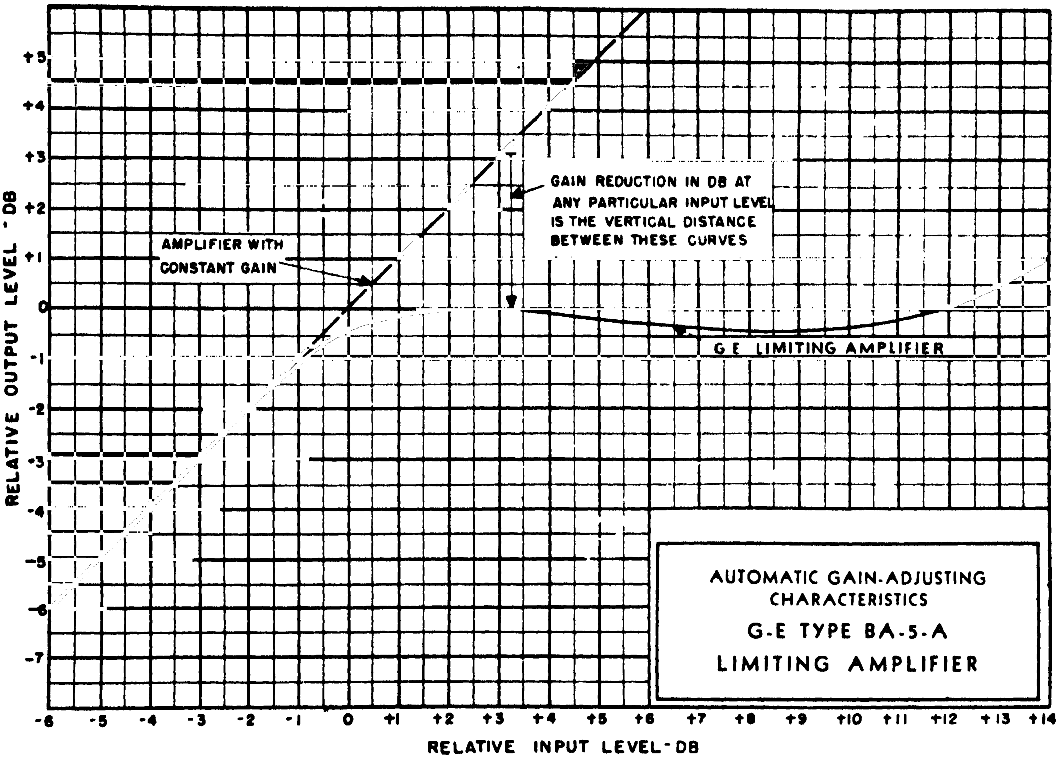

FIG. 10–4. Automatic gain adjusting characteristics of the General Electric BA-5-A limiting amplifier.

minals TB11-5 and -6 are connected to a 600-ohm terminating resistor (this may be the normal load circuit of the amplifier).

Turn the INPUT control (R11) on the front panel to the minimum gain position. Connect a signal generator adjusted to 1000 cycles with an output level of approximately −20 dbm to the input terminals TB11-1 and -3 of the automatic gain-adjusting amplifier. Turn VU MTR switch (S13) to position 2, which connects the volume indicator M11 across the output of the automatic gain-adjusting amplifier. Adjust the VU MULT control (R59) to +12 dbm. Next set the DC MTR switch S12 to G-R position, in which position M12 indicates approximate gain-reduction.

Increase the input level slowly with the INPUT control (R11) while observing the output level on M11 and the gain-reduction indication on M12. The output level should increase in a linear manner until M12 begins to indicate the verge of gain-reduction. The output should reach a maximum level, which we shall call the 0 db relative output level point, when the gain-reduction meter reads 3 to 4 db. As the input level is increased up to the point of 8 to 10 db gain-reduction indication, the output level should have dropped 0.4 to 0.5 db from its previous 0 db relative level at the 3 to 4 db G-R point. Still further increase in input level to approximately the 12 db G-R point will cause the output level to increase until it again reaches the previously established 0 db relative output level. Refer to Figure 10–4 and adjust SLOPE control (R90) until a close approximation to this characteristic is obtained. After each readjustment of the SLOPE control, always allow the gain of the amplifier to recover completely, as indicated by the G-R meter, before rechecking the gain control characteristics.

It will probably be found that during intial adjustments the output level will not remain within the range of the volume indicator +12 position. It is therefore recommended that the OUTPUT control (R27) be adjusted each time the SLOPE or BAL controls are adjusted so that the VU MTR indication remains on the readable portion of the +12-dbm scale.

It must be kept in mind that M12 indicates the approximate actual amount of gain-reduction only when the automatic gain-reduction characteristic is properly adjusted.

6. *Adjustment of V15–V16 Dynamic Balance.* After the automatic gain-reducing characteristic has been adjusted, set input level so that the amplifier is just at the verge of gain reduction. This is indicated by an output VU MTR reading of ½ db below the 0 db relative output level point, and a G-R meter indication that has just started down from

the full scale point (about 29 microamperes). Turn the DC metering switch to BAL A or BAL B position (whichever reads upward). Note meter reading and increase input level in 1-db steps to a total increase of 12 db (12 steps of INPUT control above the threshold setting). Observe the reading of M12 very carefully while performing this operation; if the reading changes more than 0.5 microamperes (½ of smallest scale division) in either direction anywhere within this 12-db range of the INPUT control setting, it indicates V15 and V16 are unbalanced more than allowable. Adjust FB BAL control (R43) until the change is less than 0.5 microamperes when repeating the above procedure. Since the adjustment of FB BAL (R43) above affects the automatic gain-reducing characteristic and since the adjustment of SLOPE (R90) also affects the dynamic balance, all adjustments will have to be rechecked until the requirements of sections 5 and 6 above are met simultaneously.

If no setting of the FB BAL control will suffice to produce a sufficiently good balance of the 6J5 tubes selected for V15 and V16, replace one of these tubes with a third 6J5 and try the new pair thus formed for satisfactory balance. It is usually possible to obtain a sufficiently well-matched pair of tubes for V15 and V16 from among any four new 6J5 tubes selected at random. In fact, it is usually not difficult to locate a pair of 6J5 tubes which will show *no perceptible* drift of the reading of M12 over the entire 12 db control range, when properly adjusted.

7. *Adjustment of V15-V16 Static Balance.* Again set DC MTR switch on BAL A or BAL B positions for upward indication. Note the reading in microamperes. Set meter switch on OFF position and remove V15 and V16 from their sockets, noting their respective positions so they can be later replaced in the same sockets. Return meter switch to previous BAL A or BAL B position and read the meter again. If the reading has changed more than 0.5 microamperes another combination of tubes should be tried in the V15–V16 sockets. If another combination is tried, repeat the automatic gain-reducing characteristic and the dynamic balance adjustments before checking the static balance again. If the balance was satisfactory, care must be exercised to insure that V15–V16 are not interchanged from their previous positions.

The automatic gain adjusting amplifier is now adjusted so that any input level within its gain reduction range will give a reasonably constant output level. In order to achieve this constant output condition at all frequencies it is imperative that the automatic gain-adjusting amplifier be terminated in a *resistive* load of the proper impedance; i.e., the normal 600-ohm load that the amplifier works into should be essentially resistive over the entire frequency range. One way of insuring that this requirement is satisfactorily met is to set up at least 6-db attenuation in the output pad R58. As shipped, R58 is wired for zero loss, but any desired value of attenuation up to 40 db can be inserted by simple soldering operations.

8. *Adjustment of Output Level.* Proper adjustment of the output level is carried out in the following manner. Connect the volume indicator M11 to the output of the amplifier by turning VU MTR switch (S13) to position *2*. Connect the output terminals TB11–5 and –6 to the input of the equipment which it is desired that the limiting amplifier feed. With a 1000 cycles input [1] of such level that the amplifier reduces gain 3 to 4 db, adjust the OUTPUT level control (R27) until the output level as read on M11 is + 12 dbm. If the range of OUTPUT control R27 is found to be inadequate for this adjustment, the attenuation of R28 will have to be changed. This output level will be found to give optimum performance. Now adjust R58 so that the maximum input level requirement of the terminating equipment is met. Any further output level adjustments required in the application of the equipment may be made with the OUTPUT level control (R27).

9. *Adjustment of Input Level.* The INPUT control (R11) should be adjusted so that with normal program input level, the desired amount of gain reduction will be obtained, as indicated on M12 with the metering switch S12 on the G-R position. When the metering switch is on this position, M12 will indicate the amount of gain reduction provided the automatic gain-reduction characteristic and dynamic balance have been properly adjusted. It must be remembered that this gain-reduction indicator will not read the actual degree of gain reduction on peaks of short duration with accuracy, due to the dynamic inability of the G–R meter to follow instantaneous peak voltages; therefore, care should be exercised in making this adjustment.

The INPUT control (R11) should first be adjusted so that with normal program input level (corresponding to 100-percent modulation of the transmitter) the program peaks just reach the verge of gain-reduction as indicated by an occasional kick of M12 with the DC MTR switch (S12) on the G-R position. The calibrated input control can then be increased in db steps to obtain the desired amount of gain reduction. This method of setting the input control for the desired amount of gain reduction is better than attempting to use the gain-reduction indicator, since this meter will not read the actual degree of gain reduction on peaks of short duration with any more accuracy than an ordinary volume indicator.

10–5d. General—Approximately one hour of tube warm-up is required before completely stabilized operation is assured. Therefore, it is of the utmost importance to repeat the adjustment proce-

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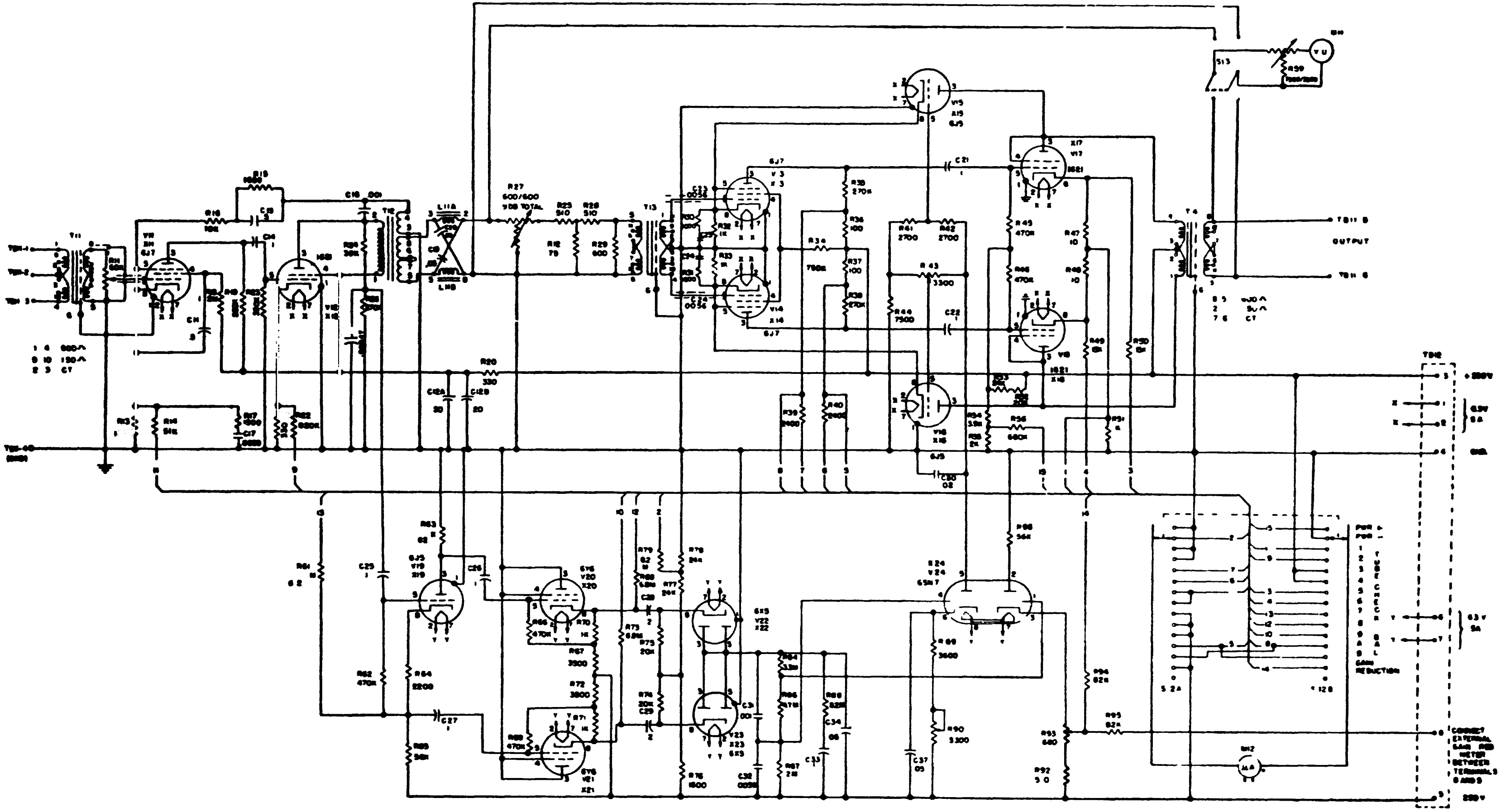
[1] If the equipment to be fed has a frequency response such that it will overload at some frequency other than 1000 cycles at a *lower* input level, that frequency should be used instead of 1000 cycles.



NOTE ALL RESISTANCES ARE IN OHMS AND ALL CAPACITANCES IN MICROFARADS UNLESS OTHERWISE NOTED

FIG 10–5 Wiring schematic of General Electric BA-5-A limiting amplifier.

dure carefully after one hour or more of continuous operation.

To insure the continuous superior performance of which this amplifier is capable, it is advisable to check its adjustment at weekly intervals. Make no changes from the previous adjustment unless at least one hour of warm-up time has been allowed.

10–6. W. E. 1126C Program Operated Level Governing Amplifier—The Western Electric 1126C amplifier is designed to be used between the studio output and the transmitter input to reduce excessive peaks protecting against (1) overmodulation in AM with its potentially inherent interference, (2) overswing in FM which may cause distortion to occur in the receiver and the guard band to be overridden, and (3) instantaneous overload and consequent distortion in other transmission systems. The 1126C has an extremely short attack time. For average program use, peak level reduction will begin within the first half cycle of program frequency. This practically eliminates overloading by peaks thus permitting a higher average percentage of modulation of the transmitted carrier. This is of particular value as it provides a better coverage of the service area, for a given transmitter power.

10–6a. Description—The 1126C consists of a 126C three-stage, push-pull amplifier, 298A control panel, and 20B rectifier. It is an a-f operated, level-governing amplifier containing automatic means to reduce its gain when the input level reaches a predetermined amount and to restore the gain as the input level falls below that amount.

The self-contained automatically regulated power supply stabilizes the operation of the amplifier over a wide range of power supply conditions. For convenience in installation, the 1126C amplifier can be separated into three units. The control panel can, for example, be mounted in a control desk and the power supply unit at the base of a rack containing the remainder of the circuit equipment, thus lending itself to flexibility in installation.

10–6b. Specifications

1. *Frequency response:* Flat within ± 1 db over the range 50 to 15,000 cps.
2. *Output noise:* — 45 dbm unweighted. Signal-to-noise ratio: 69 db at point where gain reduction starts (+ 24 dbm).
3. *Output distortion:* For program: less than 1% for all operating conditions up to 5 db compression. For single-frequency tone: (a) below compression, less than 1%; (b) for 5-db compression, less than 1% for frequencies above 200 cps and not more than 1.75% for frequencies as low as 50 cps.
4. *Compression ratio:* 10:1 (10-db input increase results in 1-db output increase above point at which gain reduction starts).
5. *Recovery time:* Variable in 5 steps of 0.2 second each from 0.2 second to 1.0 second. Optional adjustment permits variation from 0.1 second to 0.5 second.

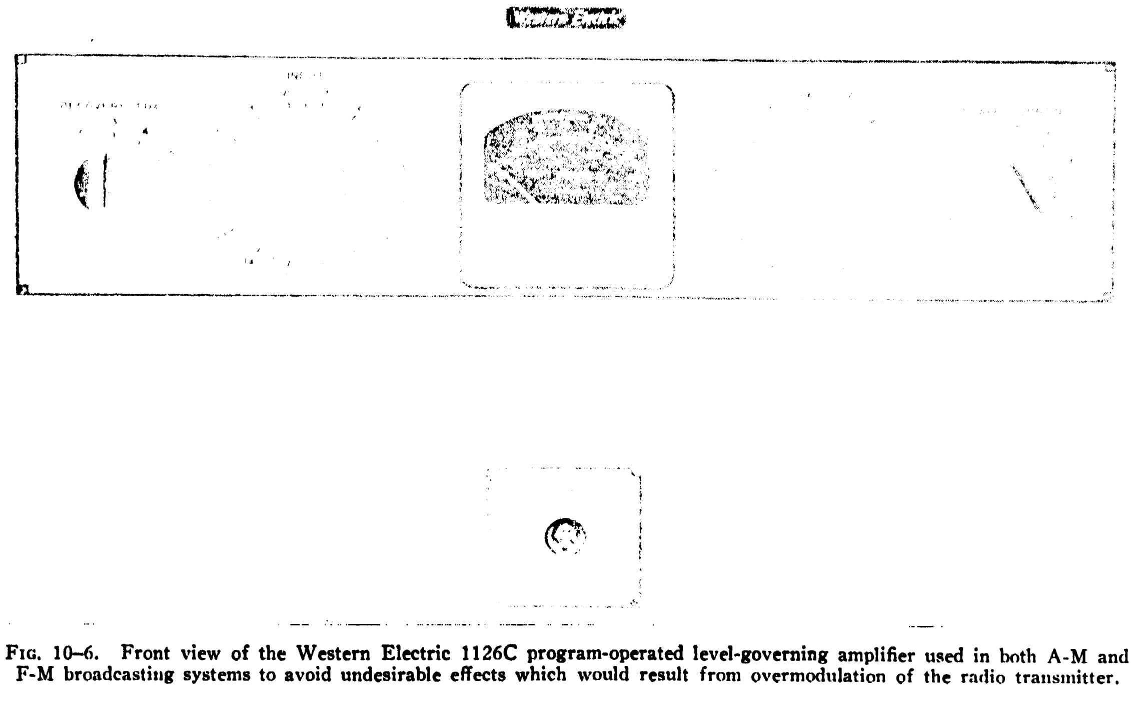


FIG. 10–6. Front view of the Western Electric 1126C program-operated level-governing amplifier used in both A-M and F-M broadcasting systems to avoid undesirable effects which would result from overmodulation of the radio transmitter.

6. *Source impedance:* 600 ohms (circuit not balanced to ground).

7. *Load impedance:* 600 ohms (circuit not balanced to ground).

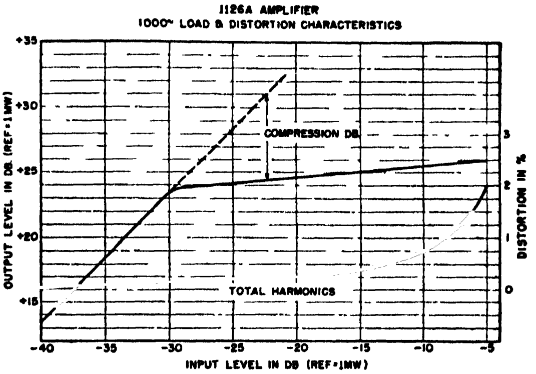


Fig. 10–7. Compression characteristics of Western Electric 1126C amplifier. (Courtesy Western Electric.)

8. *Maximum gain:* 53.5 db maximum with all input and output fixed attenuators omitted (37 db as shipped with 10-db input and 6.5-db output attenuators connected) when working from 600 ohms and into 600 ohms, both adjustable attenuators at zero.

9. *Input level range:* −30 dbm to +20 dbm (single-frequency tone).

10. *Output level range:* −6 dbm to +23.5 dbm (single-frequency tone).

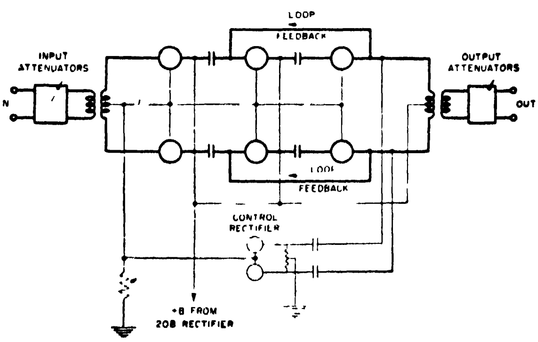


Fig. 10–8. Simplified schematic of Western Electric 1126C program-operated level-governing amplifier.

11. *Program level range:* Deduct 10 db from input and output level to allow for peak factor.

12. *Output power:* +17 dbm single frequency (as shipped and with adjustable output attenuator at zero) when gain reduction starts. (+23.5 dbm maximum, with all output fixed attenuators omitted.)

10–7. Audio Facilities for Broadcast Transmitter Plant—Figure 10–9 shows, in block diagram form, an audio facilities design typical of that employed in many modern broadcast plants. This arrangement incorporates many desirable features and conveniences which are discussed in the following paragraphs.

As can be seen, two incoming program lines from the studios have been provided, a regular line and an emergency line. Both lines carry program at all times. Each line is provided with a line coil, line equalizer, and line volume control. The volume controls may be either the ladder or the bridged-T type. The output of the volume controls are connected to two of the three input positions of a double-pole, triple-throw "program" key switch.

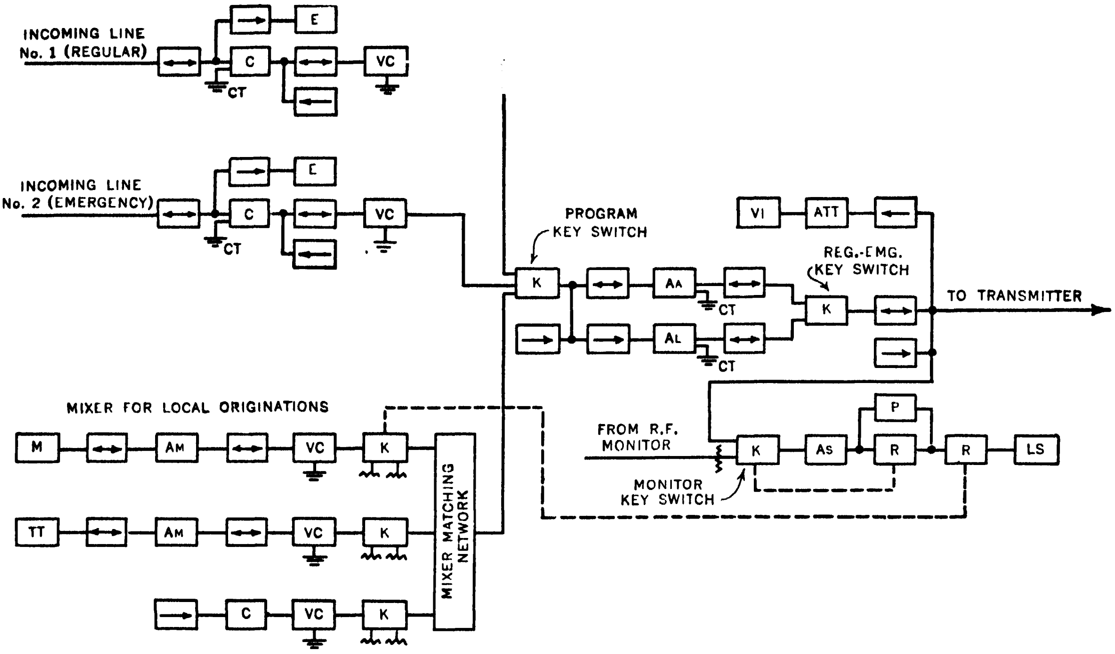
A three-position mixer has been provided for the purpose of originating programs directly from the transmitter plant in the event that both program lines from the studios should fail. This mixer provides a microphone position, a transcription turntable position, and a utility input position. This latter position is provided with a line coil at its input with no ground connection on the input winding, thereby permitting its use with either balanced-to-ground or unbalanced-to-ground circuits. The output of this three-position mixer is connected to the third input of the three-position program key switch.

When announcements are made, the operation of the microphone circuit key switch energizes a relay in the monitor circuit which "cuts" the monitor loud-speaker to prevent acoustic feedback.

The program key switch serves to select either Line 1, Line 2, or the local origination facilities. The program circuit selected by means of this key switch is connected through to the program amplifiers. The number 1, or regular amplifier, is an automatic gain adjusting amplifier, while the number 2, or emergency amplifier, is a bridging amplifier which is bridged across the input of the regular amplifier. It would, of course, be possible to employ two automatic gain adjusting amplifiers, but inasmuch as the emergency amplifier is employed only at times when trouble develops in the regular amplifier, this would be difficult to justify economically because of the higher cost of the automatic gain adjusting type of amplifier. The output of each of the amplifiers connect to either side of a "regular-emergency" key switch, the output of which connects to the line feeding the input of the transmitter. When this key switch is in the "regular" position, program is fed to the transmitter from the automatic gain adjusting amplifier. Should a failure of any kind occur in this amplifier, throwing this key switch to the "emergency" position substitutes the emergency amplifier in the circuit.

It is considered good design practice to employ two different phases of the a-c supply for the operation of the regular and emergency amplifiers. If this is done, operation of the regular-emergency key switch effectively switches to a new a-c feed.

In a broadcast transmitter, aural monitoring is usually accomplished by feeding to the monitor loud-



AA	AUTOMATIC GAIN ADJUSTING AMPLIFIER	K	KEY SWITCH	VI	VOLUME INDICATOR
AL	LINE BRIDGING AMPLIFIER	LS	LOUDSPEAKER	⏚	GROUND ON ONE SIDE
AM	MICROPHONE PRELIMINARY AMPLIFIER	M	MICROPHONE	⏚CT	GROUND ON CENTER-TAP
AS	MONITORING AMPLIFIER (BRIDGING)	P	RESISTANCE ATTENUATION NETWORK	-⊢-	TERMINATING RESISTOR
ATT	V.I. ATTENUATOR	R	RELAY	---	CONTROL CIRCUIT
C	LINE TRANSFORMER	TT	TRANSCRIPTION TURNTABLE	⊣↔⊢	DETAIL OF JACK WIRING
E	LINE EQUALIZER	VC	VOLUME CONTROL		

FIG. 10–9. Block diagram of typical transmitter audio facilities.

speaker the output of an r-f monitor. The r-f monitor consists of a pick-up device and rectifier located in the output stage of the transmitter which supplies a rectified sample of the output of the transmitter. The r-f monitor therefore provides a check on the quality and over-all performance of the transmitter. As it is often desirable to compare the quality of the audio input to the transmitter with the quality of the r-f monitor, an a-f/r-f monitor key switch has been provided which permits either the r-f monitor or a sample of the audio input to be connected to the bridging input of the monitor loud-speaker amplifier. During normal operation, this key switch is always left in the r-f position to insure that over-all transmitter performance is being checked. It is therefore desirable that this monitor key switch be nonlocking in the a-f position so it cannot be inadvertently left in this position.

It is common practice during operation of a broadcast transmitter to "cut" the monitor loud-speaker when using the telephone so it will not interfere with the telephone conversation. This is an undesirable practice, of course, as a transmitter failure may possibly go unnoticed until the telephone conversation is completed. A provision has therefore been made in the facilities being discussed, whereby a resistance attenuation network with a loss of approximately 20 db is connected into the loud-speaker circuit when the monitor key switch is thrown to the center position. This 20-db pad reduces the monitor loud-speaker level sufficiently to permit use of the telephone, but still provides sufficient level for monitoring purposes. This pad is inserted in the circuit by means of a relay in the loud-speaker circuit which is energized only when the monitor key switch is in the center position. Under these conditions of reduced level, the monitor circuit remains connected to the r-f monitor.

In the block diagram of Figure 10–9, only one monitor loud-speaker located in the transmitter room, is shown. If required, additional loud-speakers can be employed. These additional loud-speakers may prove useful in such locations as the workshop, office, and antenna tuning house, if one is used.

Ample jacks have been provided in the various program circuits of the facilities illustrated to per-

FIG. 10–10. The control console at WCBS, New York. On this desk are centralized all audio and transmitter controls. (Courtesy CBS.)

mit patching a substitute unit of equipment to replace any component which may become defective during operation.

10–8. Broadcast Transmitters—Stimulated by competition, as well as by the higher standards of performance required by both the Federal Communications Commission and the industry, manufacturers of broadcast equipment are now supplying transmitters possessing vastly superior characteristics to those obtainable years ago In general, marked progress has been made in increasing the stability of frequency, extending the over-all frequency characteristics into the high-fidelity regions, and in reducing audio distortion, carrier noise, and radio frequency harmonics. Other improvements include the reduction of operating cost, addition of automatic safety devices to protect the operating personnel and equipment, adaptability to power changes, centralized controls, reliability of operation, accessibility of parts for maintenance and service, and modernistic trends in appearance.

The transmitters described in the remainder of this chapter are typical of those designed to provide all of these features. In order to give the reader an insight into present-day radio broadcasting transmitters, it has been thought best to describe one of the many transmitters of two manufacturers whose equipment is used extensively in the United States. The descriptions of the apparatus, the adjustments and maintenance instructions are taken with little change from the instruction books supplied with the equipment. The type number of all the apparatus and the peculiar language of the art have been left in the text so that the student or operator may have a better opportunity to read his way into current practice.

One must not assume that the manufacturers whose apparatus is described herein are the *only* manufacturers of broadcast equipment in keeping with good engineering practice. There are others, but obviously space would not permit a description of each.

10–9. W. E. 405A–2 and 405B–2 Radio Transmitting Equipments—The Western Electric 405A–2 radio transmitting equipment consists of the following elements: a 702A quartz crystal-controlled oscillator operating into a two-stage, radio-frequency amplifier; a two-stage, audio-frequency amplifier; a modulating amplifier stage; a power amplifier stage consisting of two water-cooled tubes in a Doherty high-efficiency circuit; plate and grid supply rectifiers; power apparatus; water-cooling equipment; and a control desk. These elements are combined for generating a constant-frequency carrier which may be modulated by a broadcast program signal, and for amplifying the modulated carrier and transmitting it to an antenna.

The Western Electric 405B–2 equipment, shown in Figure 10–11, is the same as the 405A–2, except that the tubes in the power amplifier stage are air-blast cooled instead of water cooled.

The unmodulated carrier power supplied to the antenna is 5 kw at full power, and either 2.5 or 1

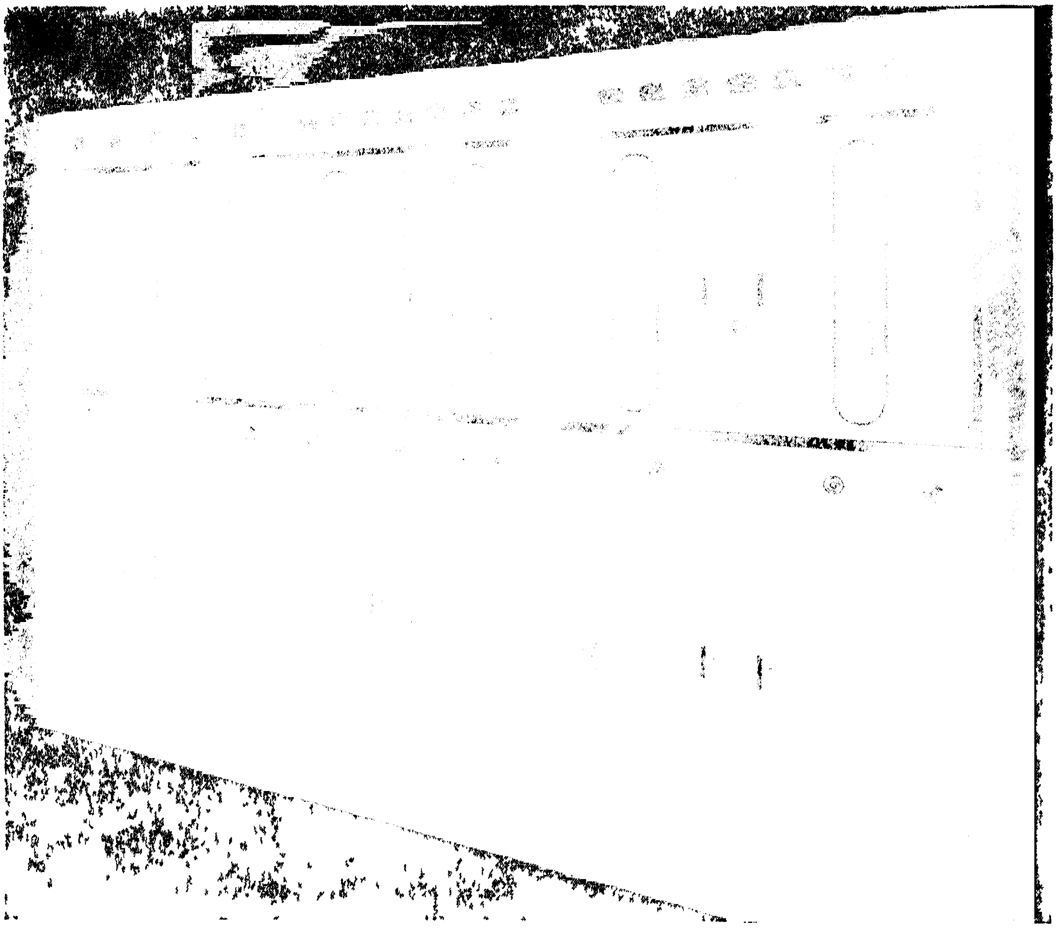


FIG. 10–11. Front view of Western Electric's 405B-2 5-kw radio broadcast transmitter. The use of the Doherty high efficiency amplifier circuit increases the efficiency of the power amplifier stage from the 30 percent usually obtained to 60 percent. Stabilized feedback is also included in this equipment.

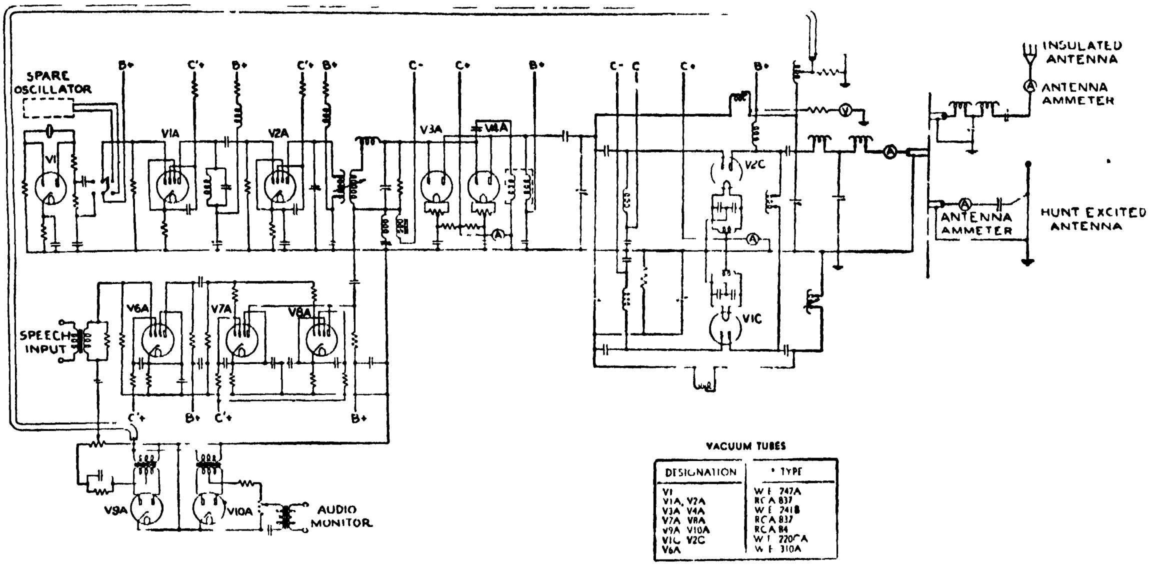
kw at reduced power. Approximately 15.8 kw is drawn from a 230-volt, three-phase, 60 (or 50 if so ordered) cycle power supply at a power factor of 0.85 to operate the equipment at its full unmodulated carrier output. During modulation by a program, the power drawn from the line varies syllabically between this value and a peak value of approximately 20 kw. At carrier outputs of 2.5 kw and 1 kw, the maximum (peak) power drawn from the line is about 16 and 13 kw, respectively. The voltage limits for the power supply are 205–250 volts with regulation not to exceed ± 10 percent, and a minimum power-line capacity of 25–30 kw is recommended.

The following table shows the approximate heat dissipated by the equipment for various operating powers, with no modulation. For average modulation, the dissipation would be slightly greater than the amount listed.

Carrier Power (kw)	Power Taken from 230V Line (kw)	Heat Dissipated by Unit Cooling System (kw)	Total Heat Dissipation (kw)
5	15.8	7.0	10.8
2.5	11.5	5.3	9.0
1.0	9.0	4.3	8.0

Protection against accidental contact with high voltage is provided by the control circuit and the manner in which the apparatus is assembled. The transmitter units are completely enclosed and are equipped with doors which cannot be opened with dangerous voltages on, nor can such voltages be applied with the doors open. In addition, interlocks are provided which require grounding of the high-voltage parts before the doors can be opened.

The operation of the transmitter is controlled by means of circuits and relays associated with the



VACUUM TUBES

DESIGNATION	* TYPE
V1	W E 747A
V1A, V2A	RCA 837
V3A V4A	W E 241B
V7A V8A	RCA 837
V9A V10A	RCA 84
V1C V2C	W E 220CA
V6A	W E 310A

Fig. 10–12. Schematic of the 405B-2, 5-kw radio transmitting equipment.

switches mounted on the front panel of the control unit. The transmitter may be started and stopped by means of these control switches. The operating condition of the various circuits is indicated by a group of signal lights.

10–9a. Electrical Characteristics

1. *Amplifier Circuit.* The use of the Doherty amplifier circuit increases the efficiency of the power amplifier stage 100%—from the 30% usually obtained to 60%—resulting in a reduction in plate dissipation which minimizes tube cooling requirements, increases stability, permits savings in space, and provides substantial economies in operation.

2. *Frequency Response.* Flat within ± 1 db from 30 to 10,000 cps.

3. *Audio Input Level.* Program level about + 12 vu (16 milliwatts). Level of single frequency for 100% modulation: + 18 vu.

4. *Stabilized Feedback.* This feature controls harmonic distortion and noise, provides high-fidelity performance in accordance with the accepted standards in this respect, and makes satisfactory a-c operation practicable with resultant savings in space, and expense by eliminating motor generator sets. This stabilized feedback is automatic in operation and independent of transmitter operating adjustment.

5. *Distortion.* A typical value of rms (or rss) audio-frequency harmonic distortion in the frequency range of 50 to 5000 cps does not exceed 4% at 85% modulation or 5% at 100% modulation.

6. *Modulation Capability.* The ability to take high program levels is another feature included in this equipment. The amplifiers are designed to carry over 100% modulation peaks without program interruption or damaging effect to circuit components or tubes. This ability is a direct result of the continued development and research in low-level modulation systems and the associated over-all stabilized feedback circuits.

7. *Noise Level.* The rms (or rss) noise level of this equipment is 60 db unweighted.

8. *Harmonic Radiation.* No radio-frequency harmonic greater than 0.03% (voltage) of the fundamental is radiated. This corresponds to better than 70 db below the output at the fundamental frequency.

9. *Method of Modulation.* Low level grid-bias modulation.

10. *Frequency Stability.* Carrier frequency is maintained well within 10 cps of the assigned frequency by means of low-temperature-coefficient quartz plate mounted within a temperature-controlled chamber.

11. *Antenna Coupling.* Antenna coupling units, which must be ordered separately, are available to couple this transmitter into a single shunt-fed or series-fed antenna or in conjunction with antenna control equipment into a multiple unit array.

10–9b. Description of Apparatus

1. *General.* The apparatus constituting the audio- and radio-frequency circuits of the transmitter is mounted in two units which, with a third unit containing the control apparatus, are mounted together to form a continuous panel front. The high-voltage transformers, rectifier unit, filter choke coil and condensers, and the power-distribution unit are located within an enclosure or room to the rear of

the main panel assembly. The water-cooling equipment (405A-2 R.T.E.) is located outside of this enclosure in any convenient location.

To facilitate reference to particular pieces of apparatus, each piece is designated by a combination of two letters with a numeral between them, such as C3A. These designations are used throughout the text of this instruction bulletin and on the drawings. In the units of the transmitter these designations are marked either on the piece of apparatus itself or adjacent to it. The first letter of the designation indicates the type of apparatus. For example, a condenser is designated by the letter "C." The number distinguishes between pieces of apparatus of the same type located in each unit. The last letter refers to the unit in which the apparatus is located. The letters designating the several types of apparatus are:

BL—Bell
C—Condenser
CB—Circuit Breaker
D—Switch
AD—Air Flow Relay
WD—Water Relay
E—Indicator or Meter Lamp
F—Fuse
G—Spark Gap
J—Jack
L—Inductance
K—Key (i.e. a switch)
M—Meter
MB—Motor-Blower
MP—Motor-Pump
PR—Protector
R—Resistance
S—Relay
T—Transformer or Regulator
TC—Thermocouple
TD—Water Temp. Alarm
V—Vacuum Tube
VS—Vacuum Tube Socket
X—Rectox Rectifier
W—Door Lock
Z—Water Valve

The letters assigned to the units and assemblies of apparatus are:

Unit	405A-2	405-B2	Equipment Unit
A	D-151215	D-151215	Oscillator Amplifier
C	D-151239	D-151218	Power Amplifier
CD	D-151164	D-151164	Control Desk
F	D-151238	D-151219	Control Unit
G	D-151224 (or D-99114)	D-151224 (or D-99114)	High Voltage Rectifier
K	D-151224 (or D-99114)	D-151224 (or D-99114)	Bias Rectifiers
P	None	None	Power Apparatus
W	None	None	Water System
	None	None	Air Cooling System

2. *Main Transmitter Assembly*

The three transmitter units in the main panel assembly are in the form of metal cabinets with doors in front providing access to the interior. The contents of the individual units are briefly summarized below:

D-151215 Oscillator Amplifier (Unit A): This unit provides for two 702A oscillators and a switch permitting either oscillator to be switched into service. The two-stage radio-frequency amplifier, and the two-stage audio-frequency amplifier are also in this unit. It also contains a grid-bias modulator and separate rectifier circuits for plate supply and grid bias.

D-151239 or D-151218 Power Amplifier (Unit C): This unit contains the high-efficiency 5-kilowatt radio-frequency power amplifier using two water-cooled or air blast cooled vacuum tubes with the necessary tuning and phasing circuits, a harmonic filter, filament current transformers and regulators and a radio-frequency protective rectifier. The coaxial transmission line to the antenna connects directly to the output of this amplifier. In the 405B-2 equipment, the D-151218 power amplifier unit also includes the motor blower and other air cooling equipment.

D-151238 or D-151219 Control Unit (Unit F): The major elements of the control system which supplies power in the proper sequence to the various parts of the entire radio transmitting equipment, together with the signal lamps and their associated relays, are located in this unit.

3. *Additional Equipment in Main Enclosure*

The following apparatus is assembled in the rear of the main panel line-up and protected by the enclosing partitions:

D-151224 (or D-99114) Rectifier (Units G and K): In this assembly are mounted the seven high-voltage mercury-vapor rectifier tubes (one spare, which is kept heated at reduced filament voltage) which comprise the three-phase rectifier supplying plate potential to the power amplifier tubes. Two single-phase full-wave rectifiers mounted on individual panels also located in this unit supply grid-bias potentials to the two power amplifier tubes.

Power Distribution Unit (DP5P): This unit contains contactors, disconnect switches and circuit breakers for the various 230-volt circuits of the transmitter.

Voltage Regulator (T2P): This unit is an automatic regulator controlling a constant potential a-c bus in the power distribution unit from which all power for the transmitter is derived. In certain cases, at the customer's option, a manually operated regulator may be supplied, instead of an automatic regulator.

Plate Transformer (T1P): This equipment consists of three single-phase high-voltage plate-supply

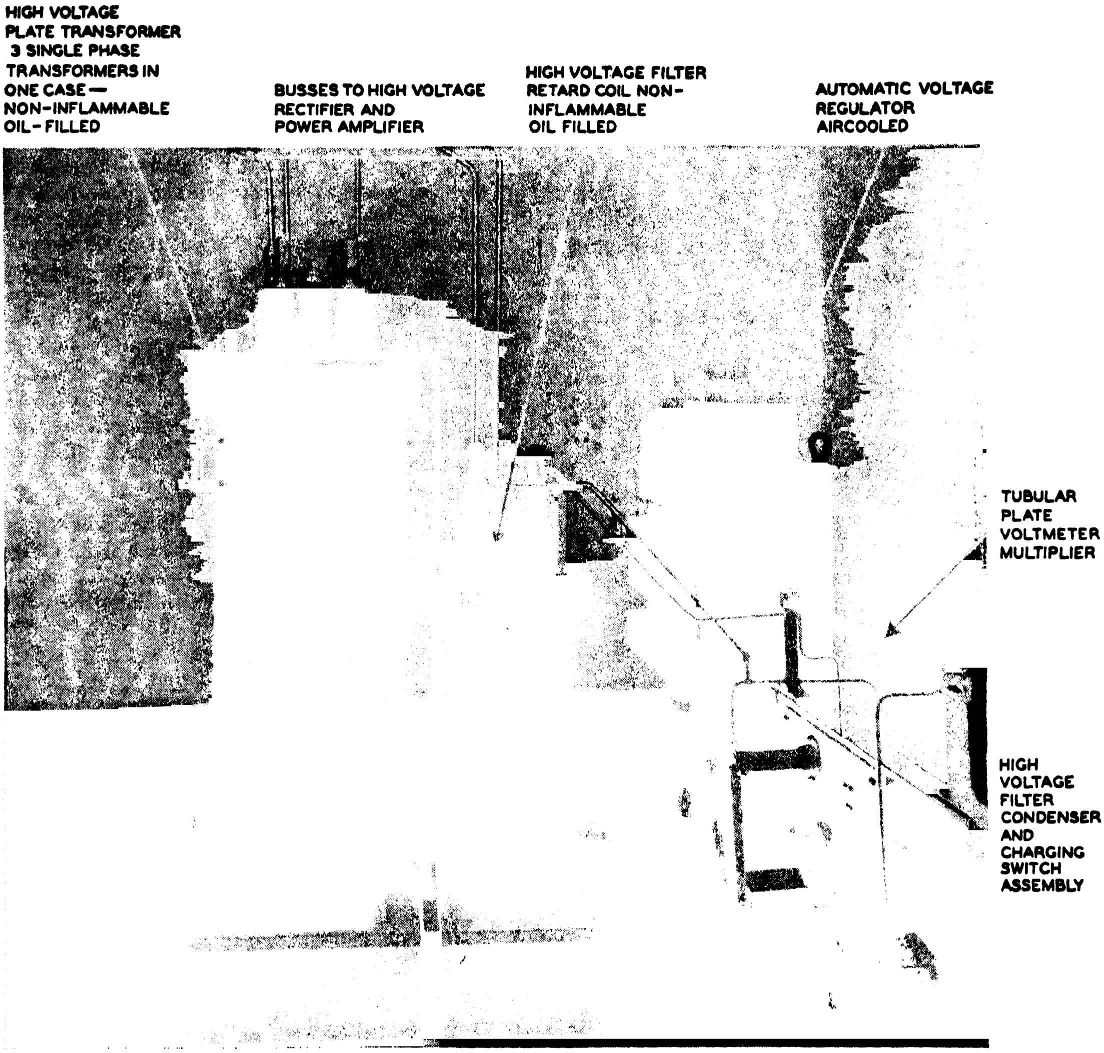

HIGH VOLTAGE PLATE TRANSFORMER 3 SINGLE PHASE TRANSFORMERS IN ONE CASE — NON-INFLAMMABLE OIL-FILLED
BUSSES TO HIGH VOLTAGE RECTIFIER AND POWER AMPLIFIER
HIGH VOLTAGE FILTER RETARD COIL NON-INFLAMMABLE OIL FILLED
AUTOMATIC VOLTAGE REGULATOR AIRCOOLED
TUBULAR PLATE VOLTMETER MULTIPLIER
HIGH VOLTAGE FILTER CONDENSER AND CHARGING SWITCH ASSEMBLY

FIG. 10–13. The power apparatus assembly of the Western Electric 405B-2 5-kw radio broadcast transmitter. This equipment is installed in a protective enclosure behind the transmitter.

transformers, mounted in one case and connected to the three-phase regulated 230-volt supply. These transformers have taps on their primary windings by which the rectified plate voltage may be changed through relay action from the control unit for full power or reduced power output. All primary and secondary taps and leads are brought to the outside of the case making it possible to disconnect any one of the transformers and run the remaining two in open delta.

Plate Supply Filter (L1P and FC5P): The power amplifier plate supply is filtered by the retard coil L1P and the condenser assembly FC5P which are located within the enclosure near the rectifier. The condenser assembly contains, in addition to the high-voltage filter condenser, its charging resistor and associated contactor and the plate voltmeter multiplier and protector.

4. *Equipment Outside Main Enclosure*

Water Cooling Equipment (W) (405A-2 R.T.E. Only): The water cooling equipment consists of a system of metallic and ceramic piping, through which water is circulated to the two water-cooled tubes, and a means of circulating and cooling the water consisting of a water pump, an air-blast radiator with its blower motor, a storage tank and the necessary valves and fittings.

D-151164 Control Desk (Unit CD): This unit provides a volume indicator, monitoring amplifier, modulation and antenna current meters, keys and attenuators for controlling various audio inputs, and remote control switches and indicating lamps for operating the transmitter.

Antenna-Coupling Unit (E): This unit is not generally supplied as part of the radio transmitting equipment. The type of antenna-coupling equipment depends on whether the antenna is of the series or shunt excited type. A separate instruction bulletin is furnished with the antenna-coupling equipment.

10–9c. Power Supply and Control Circuits

1. *Power Circuits.* The 230-volt, three-phase 60 (or 50) cycle power for the operation and control of the transmitter is fed to the various circuits through the power distribution panel (DP5P) located behind the control unit.

There are no door switches on this panel; it may be opened at any time without disturbing the operation of the transmitter. All circuit breakers are of dead-front construction.

The power for operation of all the transmitter circuits is supplied through the induction regulator T2P, the input of which is connected through CB1P, designated "230 v. SUPPLY," and terminals 4, 5 and 6. This regulator automatically maintains a voltage of 230 volts ± 1 percent on the busses connected to terminals 7, 8 and 9, provided that the supply voltage remains at all times within the limits 205–250, and that there are no rapid variations within these limits. The supply voltage on each phase before and after regulation is measured by voltmeter M1F, designated POWER SUPPLY VOLTS, in the control unit using the POWER SUPPLY VOLTMETER switch D6F.

To the regulated busses are connected the circuit breakers listed below which control the several circuits of the equipment.

CB2P—"Reg. Motor"—Protects the motor circuit of the induction regulator T2P.

CB3P—"Control Circuit"—Supplies power to the control unit through which all circuits of the transmitter are controlled.

CB4P—"P.A. Fil."—(and the relay S2P)—Control the application of power to the filaments of the power amplifier.

CB5P—is a spare circuit breaker having a blank designation plate.

CB6P—"Cooling System"—(and the relay S5P)—Protect the circuit which supplies power to the pump motor MP1P and the blower motor MB1P (405A-2 R.T.E.), or the blower motor MO1C (405B-2 R.T.E.).

CB7P—"Osc. Amp. Unit"—(and the relay S3P)—Control the power to the oscillator amplifier.

CB8P—"P. A. Bias"—(and the relay S4P)—Control power to the plates of the two bias rectifiers in the rectifier unit.

CB9P—"Rect. Fil."—(and the relay S6P)—Supply power to the filaments of the plate and the two bias rectifiers in the rectifier unit. (See Figure 10–14.)

CB10P—Motor-operated circuit breaker located in the lower compartment of the power distribution panel DP5P which controls the application of power to the high-voltage plate rectifier circuit. This motor-operated circuit breaker contains magnetic and thermal trips in addition to the no-voltage trip coil which is de-energized by the action of any of the over-load relays associated with the water-cooled tubes. Power controlled by this breaker is supplied to the high voltage rectifier transformer T1P through either relay S7.1P or S7.2P which select primary taps of the transformers making two values of rectified voltage available for full and reduced power operation.

2. *High-Voltage Filter Circuit.* The high-voltage retardation coil L1P is located with the high voltage condenser assembly FC5P behind the power amplifier unit. This apparatus serves to filter the noise from the high-voltage supply to the plates of the power tubes. The condenser assembly FC5P is provided with a resistance R2P which prevents the condensers C1.1P and C1.2P from drawing an excessive charging current when the rectifier is started. The contacts of relay S1P short circuit this resistance when sufficient time has elapsed to allow the condenser to charge to the operating voltage.

The plate voltmeter multiplier R1P and the voltmeter protector PR1P are also mounted on this assembly.

3. *High Voltage and Bias Rectifiers, Figure 10–14.* The plate rectifier circuit of this assembly contains the six mercury-vapor tubes V1G to V6G inclusive, connected in a three-phase full-wave circuit. The tubes convert the three-phase high-voltage power furnished by transformer T1P into unidirectional current which, after being filtered (by L1P and FC5P), supplies the plate current of the two power amplifier tubes. The seventh tube V7G is kept in operating condition by heating its filament at a reduced voltage obtained through resistances R3G and R4G. In case of failure of any of the other six tubes, this tube may be substituted, since it is ready for instant operation.

An overload relay S1G connected across the current shunt R1G is provided to indicate excessive current drawn from the rectifier and to open the high voltage circuit breaker. The operate point of this relay may be adjusted by means of resistance R2G.

Protection from accidental contact with the high-voltage circuits of the rectifier and other apparatus within the main enclosure is afforded by the mechanically interlocked switches D1G, D2G and D3G

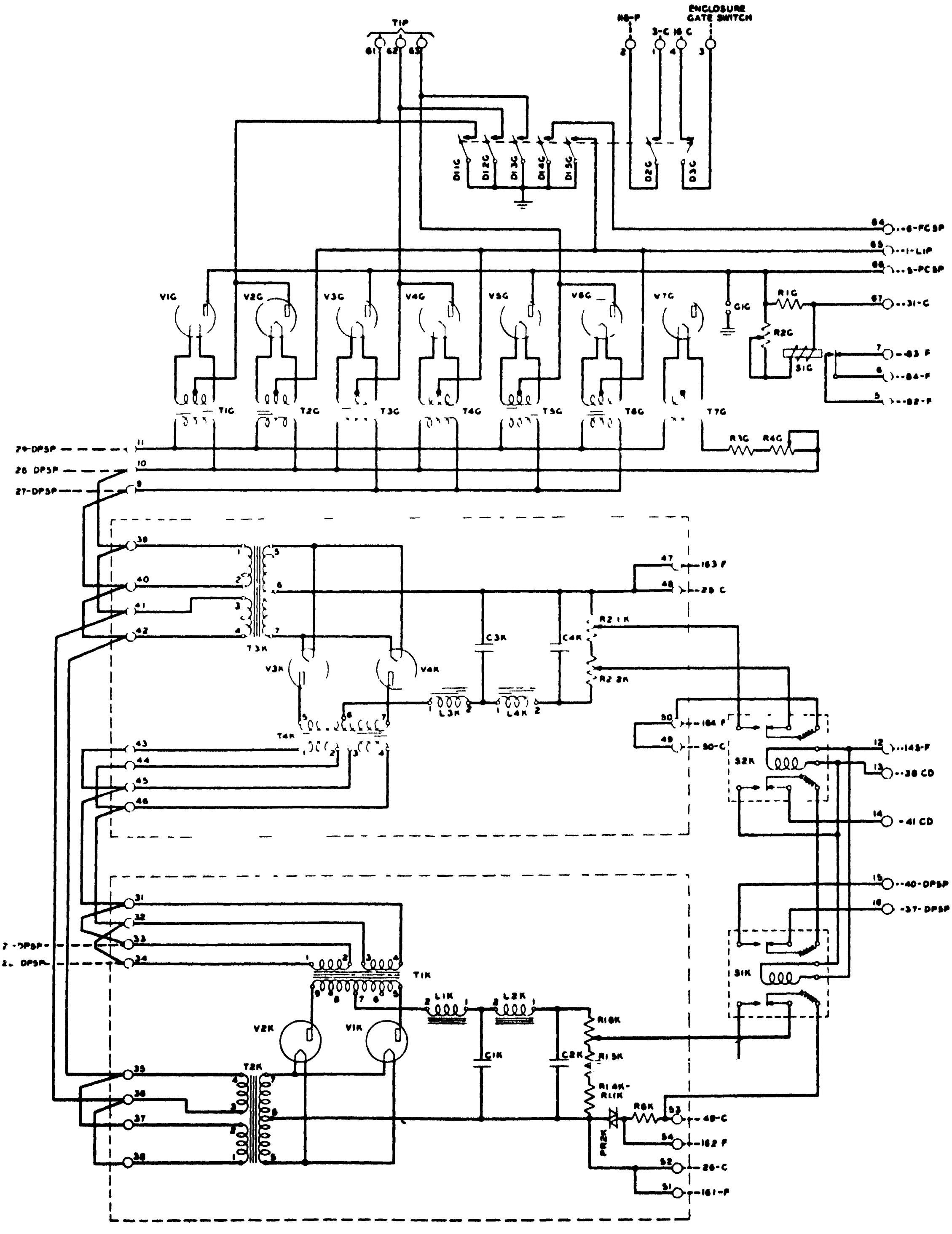


FIG. 10–14. Units G and K— D-151224 (or D-99114) rectifier.

which are operated by a hand wheel located at the enclosure gate. When operated to open the gate, D3G opens the circuit of the transmitter gate switches, which in turn opens the high-voltage circuit breaker; D1G then grounds the high-voltage supply circuit to the rectifier and also the output circuit of the rectifier; and finally D2G energizes the circuit of the transmitter door locks.

Two similar single-phase full-wave rectifiers, each using two mercury-vapor tubes, are mounted in this assembly. They supply grid-bias potentials separately to the two vacuum tubes of the power amplifier.

One of these rectifiers, consisting of tubes V1K and V2K and associated equipment, supplies a potential of approximately 450 volts when the transmitter is operating at full power of 5 kw (350 volts at reduced power of 2.5 or 1 kw) for biasing the grid of tube V2C. These voltages are adjustable by secondary taps on transformer T1K and sliders on the resistances R1K and the reduced voltage is obtained by the action of relay S1K controlled by switch D9F in the control unit. The resistance R6K is a voltmeter multiplier and PR2K is the voltmeter protector.

The other rectifier, consisting of tubes V3K and V4K and associated equipment, supplies a potential of approximately 300 volts, when the transmitter is operating at full power of 5 kw (300 volts at reduced power of 2.5 kw, or 275 volts at 1 kw) to the grid circuit of V1C. These voltages are also adjustable by sliders on R2K and the reduced voltage is obtained by the action of relay S2K controlled by switch D9F.

4. *Control Unit and Control Circuits.* The control unit is the center of the control circuits which extend throughout the system. This unit provides independent control of the oscillator amplifier, of the cooling system and amplifier filament circuits, and of the rectifier tube filaments and bias rectifiers. The high-voltage control is interlocked with these branches. With this control circuit, preheating of mercury-vapor rectifier tube filaments and testing and servicing of the various components of the transmitter may be done without sacrificing any protection of the equipment or operating personnel.

5. *Oscillator-Amplifier Filament Control.* Closing D10F, OSCILLATOR-AMPLIFIER FILAMENTS supplies 230 volts through terminal 5F to terminal 20 of the power-distribution panel DP5P. This energizes contactor S3P which supplies power from terminals 18 and 19DP to the oscillator-amplifier terminals 3A and 4A. D2A and D3A are normally in the "ON" position so that filament transformers T2A, T3A, T4A and T12A are energized.

6. *Cooling System and Power Amplifier Filament Control.* Closing D2F COOLING SYSTEM supplies 230 volts through terminal 9F to terminal 53DP, thus operating contactor S5P and supplying power to the water-circulating pump and radiator blower motor (405A-2 R.T.E.) or the blower motor in the Unit C (405B-2 R.T.E.).

Closing D2F also supplies 230 volts to a contact and to one side of the coil of relay S1F. The other side of this coil is connected through terminal 12F to a contact of the water-flow relay WD1W or air flow relay AD1C which, when operated by the water or air flow, completes the circuit of S1F to the return side. With S1F operated, the control circuit is continued through the contacts of S1F to switch D3F—AMPLIFIER FILAMENTS.

With D3F in the ON position, the control circuit through terminal 17F and terminal 16DP operates contactor S2P, energizing the filaments of the power amplifier.

7. *Rectifier Filaments, Bias Plate and Bias Delay Control.* Closing D1F RECTIFIER FILAMENTS supplies 230 volts through terminal 23F to terminal 32DP and operates contactor S6P to energize the rectifier filaments and relay S18F which insures the actual energization of the filaments before power is applied to the rectifier plate-voltage control-circuit. The 230-volt circuit is continued through the auxiliary contacts of S6P and the contacts of S18F to terminals 33DP and 24F, operating hour meter M5F and lighting E5F—RECTIFIER FILAMENTS. Delay relay S2F is energized, and through L1F 115 volts is supplied to terminals 1 and 2 of S16F. A detailed description of the operation of S16F, which controls the reheating of the rectifier tubes in case of power failures, is given under the paragraph "Power Interruptions." Under original starting conditions S16F will operate, closing the contacts connected to its terminals 3 and 4 about 18 seconds after S16F is energized. Three minutes after S2F is energized, its contacts close and operate S3F. The control circuit continues through the contacts of S2F and S3F in parallel, then through the contacts of S16F to relay S4F which locks itself up from a point on the control circuit ahead of the contacts of S2F. K1F, a momentary-contact push button is bridged from ahead of the S2F contacts directly to S4F and may be used to operate S4F instead of waiting for the delay relays to perform that function. The control circuit continues through the other set of contacts of S4F to light E10F RECTIFIER FILAMENT DELAY and then goes to D11F OSCILLATOR AMPLIFIER CONTROL.

8. *Oscillator-Amplifier Bias and Plate Control.* With D11F in the OPERATE position, the circuit is connected through terminal 30F to terminal 6A, through the oscillator-amplifier door switches D9.1-9.4A and terminals 7A to 31F, and through D11F again to 32F. Door switches for the antenna-coupling unit are connected between 32F and 33F. From terminal 33F the control circuit continues through the door switches in the power amplifier unit, the rectifier unit and the high-voltage rectifier grounding switch, then returns to the control unit at terminal 36F. From terminal 36F one branch is

connected through D11F in the OPERATE position to terminal 26F, then through terminal 10A to relay S2A, which applies power to the plate circuit of the bias rectifier in the oscillator-amplifier. The control circuit also passes from terminal 10A through the plate-voltage switches D4A and D5F to the relay S3A, which operates through contacts on S2A. Thus, if S2A has operated, supplying grid bias to the amplifier tubes, the contacts of S2A and S3A are closed, supplying power to the high-voltage transformer of the plate voltage rectifier. Overload protection of the oscillator-amplifier power tubes is effected by relay S7A, which is operated by excess plate current through R85A and is locked up by voltage from the bias rectifier circuit. Operation of S7A closes contacts, short circuiting the winding of S3A, thus removing power from the plate rectifier circuit. It should be noted that in case of an overload on the 1500-volt output of the plate rectifier in Unit A, relay S7A will not operate, but fuse F3A may blow. In this case plate voltmeter M3A will continue to read the voltage difference between the two positive outputs of the rectifier (about 1500 volts).

9. *Power Amplifier Bias Control.* The other branch of the control circuit from terminal 37F is connected through 43F and 23DP to the contactor S4P, the operation of which energizes the plate circuit of the bias rectifier, thus supplying grid potential to the power amplifier.

10. *Power Amplifier Plate Potential Control.* The control circuit for operation of the power amplifier plate-supply rectifier is common with the power amplifier filament control from D2F through S1F, D3F and S2P. At this point the circuit is connected through the auxiliary contacts of S4P to terminal 53F. This interlocks the control of the high-voltage plate supply with that of the filament and bias supplies.

From 53F the circuit is connected through the HIGH VOLTAGE RECTIFIER switch, D4F, to terminals 56F, 57F, 63F and 52DP and thence to one side of the motor which operates circuit breaker CB10P. Operation of this breaker applies voltage to one side of each of the three-phase windings of the high-voltage plate-supply transformer.

From 57F control voltage also energizes S10F, the contacts of which close the 24-volt d-c supply circuit to the under-voltage release coil of the circuit breaker. After the breaker is closed, current through this coil holds the breaker closed.

The closure of CB10P, or its reclosure after an overload or under-voltage has tripped it, is controlled by relays S8F, S9F, and the reclosure relay S12F. The control circuit from 57F applies voltage to one contact of S8F and one side of S12F, and through a back contact in S12F to 58F and thence to 59F through an auxiliary switch in the circuit breaker which is closed when the circuit breaker is open. From 59F, relay S8F is energized through the back contact of S9F. Relay S8F locks up through one contact and through the other contact energizes S12F and the circuit breaker closing motor through terminal 62F. (Note: If S8F fails to lock up make sure that its contacts operate in the sequence as noted on Figure 10–15.) S12F latches up. When the circuit breaker closes, its auxiliary contacts close, connecting terminals 60F and 61F to the return side of the control circuit. Through 61F, relay S9F is energized; S9F locks up through the make contact and deenergizes S8F through the break contact. When S8F releases, the motor mechanism on the circuit breaker and the operate coil of S12F are deenergized and S9F is released. Through 60F, relays S13F and S14F are energized. S14F extinguishes lamp E27F, CIRCUIT BREAKER OPEN, and completes the circuit of S50F to the positive of the 24-volt relay circuit. S13F is a delay relay, after 2 seconds it operates to energize S1P, the contacts of which short circuit the charging resistance in series with the rectifier filter condenser. E26F CIRCUIT BREAKER CLOSED, is energized through 60F as is the timing motor in S12F. If the breaker remains in the closed position for a period equal to or longer than the present adjustment of the timing motor, the release coil in S12F will be energized and restore S12F to normal. If for any reason the circuit breaker is tripped by the overload circuit the above closing sequence is again started by the auxiliary contact of the breaker between 58F and 59F. If, however, the breaker is tripped out before the timing motor resets S12F, the breaker will remain open until the manual push button K2F, CIRCUIT BREAKER RECLOSE, is operated to energize S8F.

11. *Overload Tripping Circuit.* The plate circuit breaker, CB10P, is equipped with both instantaneous and inverse time a-c tripping elements as well as the d-c under-voltage release coil. In case of large overloads such as those caused by arc-backs in the rectifier tubes, the a-c trip elements open the breaker directly. The under-voltage release coil is supplied from the 24-volt rectifier X1F through the series resistance R31F. The armatures of the overload relays, S1C, S2C and S1G are connected to the positive side of the 240 volt supply. The make contacts of these relays are connected across the under-voltage release coil so that the operation of an overload relay short circuits the coil, thus tripping the breaker. The back contacts on the overload relays connect to holding windings of associated lamp relays, the circuits of which are completed by contacts to the negative side of the 24-volt supply. The operate windings of the lamp relays are connected to the + 24 volts bus on one side and return to the negative side of the supply through LAMP RESET key K3F. The lamps are energized from the secondary of T2F through the lamp contact of each relay. This circuit thus provides that an overload in the power amplifier or plate rectifier

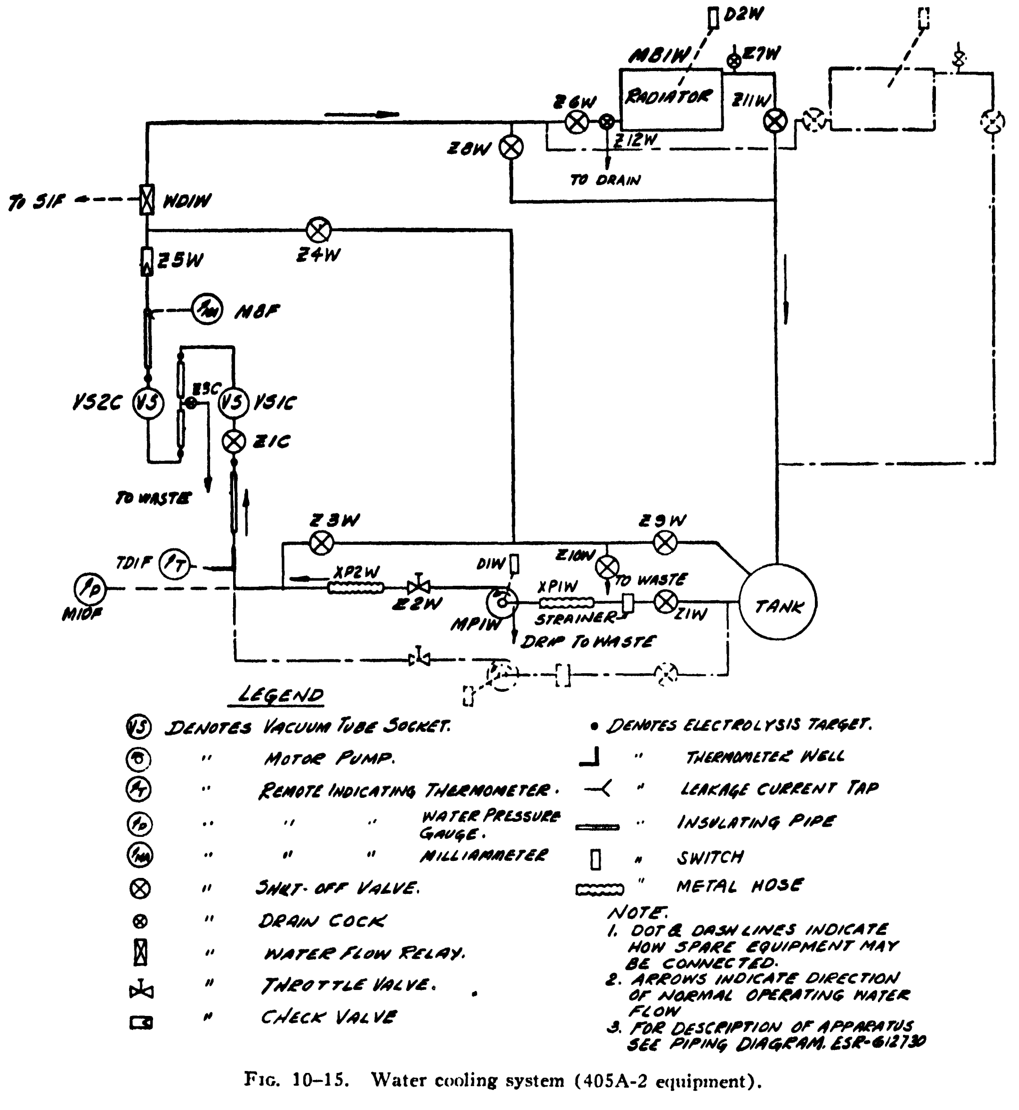


FIG. 10–15. Water cooling system (405A-2 equipment).

will trip the circuit breaker which supplies power to the plate rectifier and will extinguish a corresponding overload indicating lamp.

12. *Reduced Power Control.* As previously stated, the operation of the circuit breaker CB10P supplies the 230-volt, three-phase regulated power to one side only of each of the three primary windings of the plate-supply transformer, T1P. The circuit to this transformer is completed through either contactor S7.1P or S7.2P, depending on the operation of switch D9F to REDUCED POWER or FULL POWER.

In the FULL POWER position the control circuit passes through 42F, 14K and the back contacts of relays S2K and S1K in series to contactor S7.2P, which operates and completes the power circuit to the primary windings of T1P through taps which give full plate voltage. Another set of back contacts on S2K and S1K close the grid-bias circuits of the two power amplifier tubes, V1C and V2C, to the full negative voltage taps on R2K and R1K, respectively, which are load resistances of the bias rectifiers.

In the REDUCED POWER position of D9F, the control circuit is carried through terminals 41F and 13K to the windings of S1K and S2K and through the windings to the return circuit. The relays are thus operated, completing the control circuit through make contacts of each relay to contactor S7.1P, which operates and transfers the connections to the primary windings of T1P to taps which give reduced plate voltage. Other make contacts on S1K and S2K close the grid-bias circuits of the power amplifier to reduced voltage taps on R2K and R1K. In the REDUCED POWER position of D9F, relay S17F is also operated, supplying 24-volt power through terminals 39A and 40A to relay S9A, operation of which reduces the speech input and bias on the first radio-frequency amplifier tube.

13. *Power Interruptions.* When the rectifier filament circuit is energized, 230 volts from the control circuit is applied to auto-transformer L1F, which in turn supplies 115 volts to terminals 1 and 2 of S16F. Rectox RF1 and condenser C1 then provide a d-c voltage across voltage divider R3. Condenser C2 starts charging through R1. When the voltage across C2 reaches the proper value, V1 breaks down and starts conducting between the two principal electrodes. As soon as the tube starts conducting there will be a conducting path established from the third electrode to one of the main electrodes. Relay S1, in series with this third electrode, will operate and close its contacts connected to terminals 3 and 4. The back contact removes an equivalent load from the circuit when the relay is energized. If S16F is de-energized, C2 will discharge through R1 and R3 and for a very short time will maintain a current between the electrodes through R2. If voltage is reapplied while the condenser is still at sufficient voltage to be maintaining the current between the electrodes through R2, relay S1 will operate immediately. If, however, C2 has discharged to such a value that the tube is no longer conducting between the electrodes when the power is reapplied, C2 must be recharged to the value necessary to break down the tube. The time required to recharge C2 will be a function of the length of time C2 has been discharging. Hence, the delay in the operation of S1 will be proportional to the length of time power is off. If C2 is completely discharged the delay on S1 will be approximately 18 seconds. If the power interruption occurs after V1 has broken down, C2 will maintain the conduction in the tube for about one-half second. If the power is reapplied during this half-second, S1 will operate immediately. For any other condition of charge on C2, there will be up to 18 seconds delay in the closing of S1.

S16F is energized at the same time as S2F. S4F is operated through the contacts of S16F and S2F in series. When S16F and S2F are energized, S16F will close its contacts in about 18 seconds. In about 3 minutes, S2F will operate and energize S4F which locks up. S3F is also operated. In case of a power interruption, S4F and S2F will release. However, S3F whose contacts are in parallel with S2F, will not release for a period of about seven seconds. If power is reapplied during this seven-second period, S3F will be locked up and S16F will be operated after the delay explained above. As soon as S16F operates, S4F will lock up and the transmitter will be restored to operation. If the power interruption is longer than the seven-second period the full delay for the operation of S2F is required before S4F is locked up. Thus, for power interruptions up to about seven seconds, the delay for reheating the rectifier filaments is controlled by S16F, and the delay is proportional to the length of power interruption.

14. *Radio-Frequency Protective Circuit.* The operation of the radio-frequency protective circuit is accomplished by relays S3C and S10A. The adjustment of this circuit is described in the section covering the power amplifier. Relay S3C operates to close its contacts when any change occurs to disturb a balance between the input and output circuits in the power amplifier. The contacts are in series with the winding of relay S10A, PROTECTIVE CIRCUIT switch D12F, and the 24-volt source. The operation of S10A closes one pair of contacts which increases the bias on V1A and thus blocks the output from the oscillator. The back contacts of S10A are opened, taking power off the lamp relay S51F.

15. *Oscillator-Amplifier Testing Control.* If it is desired to operate the oscillator-amplifier unit for testing or servicing, switch D11F may be thrown to the TEST position. This acts to open the door-switch chain in so far as the operation of the control circuit of the rest of the equipment is concerned. Power for the control of the unit is then taken from the power supply to the oscillator-amplifier. From 5A, one side of the 230-volt supply is connected through 28F, D11F and 30F to 6A, through the door switches D9A to 7A, 31F, D11F and 29F to 25F and 13A to S2A. The other side of S2A returns to the other side of the 230-volt power supply through 26F, D11F and 27F. Operation of S2A applies power to the plate circuit of the bias rectifier. It also closes the circuit of relay S3A through R66A, 16A and the switches D5F and D4A to 26F and thence through D11F and 27F. Operation of S3A supplies power to the plate-voltage rectifier.

With D11F in the TEST position, there is no automatic delay for the protection of the rectifier tubes in the oscillator-amplifier. *Be sure that the filaments of this unit are energized at least 15 seconds before the "Plate Rectifier" is turned* ON.

Also, with D11F in the TEST position there is no protection against the oscillator-amplifier plate and bias potentials in the rear of this unit, since the door switch of the enclosure door has been disabled. Therefore, *the operating personnel should not be permitted to conduct any work within the enclosure while D11F is in the* TEST *position. The purpose of this switch is only to permit the operation of the oscillator-amplifier without energizing the other units of the equipment.*

16. *Control Desk Circuits.* The apparatus of this desk is mounted on three hinged panels, and provides the following facilities:

Panel 1

Western Electric 754A Volume Indicator
Western Electric 124E Amplifier (Monitoring)

Panel 2

Extension meter (M1CD) for modulation monitor of speech-input equipment
Volume Indicator meter (M2CD)
Remove antenna or transmission-line ammeter (M3CD)
Keys which function as follows:
- K1CD—Switches the output of the announcing microphone pre-amplifier into circuit, and cuts off monitor loud-speaker.
- K2CD—Switches the output of the transcription amplifier into circuit. May be left on with K1 to mix transcription and announcing microphone.
- K3CD—Switches into circuit either the K1-K2 selection or audio oscillator tone for test purposes.
- K4CD—Switches into circuit either the K3 selection, or K5 selection.
- K5CD—Switches into circuit either of two program lines.
- K6CD—Switches input of monitoring amplifier between audio input and rectified output of radio transmitter.

Attenuators to provide volume adjustments as follows:
- P1CD—Announcing microphone
- P2CD—Transcription
- P3CD—Lines from studio

Receptacle (J1CD) with cap, for announcing microphone
Twin Jack (J2CD) for twin telephone plug

Panel 3

Power-supply circuits with switches (D1-D5CD) and indicating lamps (E1-E5CD) for one 220-volt and four 110-volt supplies (to tower lighting circuits, speech input equipment, etc.). One of the 110-volt supply circuits is connected to the component monitoring amplifier.
Remote-control switches and indicating lamps multiplied from Unit F.

It will be noted that the microphone-transcription output is brought out to terminals 59 and 60 to permit the connection of an amplifier at that point, if desired. If not, strap terminal 59 to 57 and terminal 60 to 58. All speech circuits are 600 ohms impedance except the monitoring amplifier output, which is 8 ohms, and the announcing microphone circuit, which depends on the microphone used.

Meter M3CD is operated from thermocouple TC2C in Unit C, connected to the transmitter output through a small variable condenser C31C. The reading of M3CD is adjusted to the correct value by varying C31C.

The transmitter-control switches D6 to D11CD inclusive on Panel 3 are three-way switches, functioning with those of corresponding nameplate designations on the control unit of the transmitting equipment. The full-reduced power transfer switch D12 is a DPDT switch, which in effect reverses the position of switch D9F of the control unit. If either D9F or D12CD is operated to change the power while the transmitter is on the air, the "OSC.-AMPL. OVERLOAD RESET" button (K5F, or D13CD, respectively), should be held in while the transfer switch is thrown.

10–9d. 405A–2 Water-Cooling System (Figure 10–15)

1. *General.* The water-cooling system of the 405A–2 equipment is designed to maintain within safe operating limits the temperature of the power amplifier vacuum tubes V1C and V2C. The vacuum tubes are cooled by the circulation of distilled water around their anodes. The water, in turn, is cooled by circulation through a radiator from which the heat is carried off by a fan-driven stream of air. The system, which is simple in principle and operation, consists of a water reservoir, a pump which circulates the water, a radiator, and a few convenient valves and protective devices.

Because the vacuum-tube water jackets are at plate potential it is necessary to insulate them effectively from ground. This insulation is provided, in so far as the water cooling system is concerned, by long lengths of ceramic tubing in the D-151239 power amplifier leading the water to and from the tube jackets and is effective as long as the distilled water remains uncontaminated. It is, therefore, important that, before operation of the vacuum tubes is attempted, any loose dirt or solder flux be completely flushed out of the system and nothing but high-grade distilled water be used for regular service.

A constant check is kept on the effectiveness of the insulation of the water connections by the leakage current meter (M8F) which indicates the current to ground through the water. This meter reading normally does not exceed 2.5 ma and the water system should be drained and refilled with clean water if the leakage current exceeds this value.

The safety devices for the protection of the vacuum tubes consist of an alarm-operating thermometer (TD1F), to warn of the approach of the water temperature to the maximum upper limit, and the water-flow indicator (WD1W) which serves automatically to disconnect the high-voltage and filament supplies to the tubes if insufficient water flows through the tube jackets. The water-flow indicator should be set to shut off at 5 gallons per minute.

2. *To Fill the System*

Close all except the following valves:
Pump inlet valve Z1W

Pump outlet valve Z2W
Jacket inlet valve Z1C
Radiator inlet valve Z6W
Radiator outlet valve Z11W

Pour about 25 gallons of distilled water into the tank.

Start pump and adjust throttle valve Z2W for a flow of 7 gallons per minute as shown on the water-flow indicator WD1W.

Remove air from system by opening radiator vent cock Z7W until water appears there.

If necessary add enough water to have one foot depth in tank with pump running.

3. *To Empty System*

Stop pump MP1W by opening switch D1W

Open the following valves:

Waste valve Z10W
Tank drain valve Z9W
Amplifier drain valve Z3W
Amplifier drain valve Z4W
Radiator bypass valve Z8W
Radiator vent cock Z7W
Amplifier drain cock Z2C

When system is empty, close the valves listed above.

4. *Adjustment of System*

For normal operation, the following valves are kept full open:

Pump inlet valve Z1W
Jacket inlet valve Z1C
Radiator inlet valve Z6W
Radiator outlet valve Z11W

All other valves are kept closed except throttle valve Z2W, which should be adjusted for a flow of about 7 gallons per minute, or enough to close relay contacts in indicator WD1W when indicator is adjusted to open relay contacts at 5 gallons per minute. The contact adjustment is accessible through a small hole in the front of the indicator protected by a swinging dust cover. The adjustment is made with a screwdriver. No readjustment should be required after the initial installation setting.

5. *Precautions against Freezing.* If the radiator is exposed to freezing temperature, the following simple precautions must be observed to guard against the freezing of water in the radiator.

When the radiator is exposed to freezing temperature, do not circulate cool water through it and do not circulate hot water through it too slowly.

When shutting system down in freezing weather, drain radiator quickly by opening vent cock Z7W, and drain cock Z12W and radiator bypass valve Z8W. When radiator is empty close radiator inlet valve Z6W.

When starting in freezing weather, be sure that the radiator is empty, inlet valve Z6W and outlet valve Z11W are closed, and bypass valve Z8W is open. When the water temperature reaches 120 degrees Fahrenheit, close drain cock Z12W, open radiator outlet valve Z11W and inlet valve Z6W, and close bypass valve Z8W and vent cock Z7W. *Do not start the radiator fan* until the water temperature again rises to 120° F and *shut off the radiator fan* if the water temperature falls below 70° F.

In any weather, it is not necessary to run the radiator fan until water temperature rises to 100° F.

6. *Electrolysis Targets.* Because an electric current, however small, is flowing through the water in the porcelain piping, there is a consequent transfer of metal from the high-voltage to the ground-voltage end of the system. To guard against this metal being taken from the water fittings themselves, replaceable "Electrolysis Targets" are provided at four fittings beneath and attached to the vacuum-tube sockets. These hexheaded targets enter the pipe diagonally and are accessible from the front of the amplifier. They should be removed and inspected at intervals of about one month and replaced by new targets when necessary to insure that the target wire always extends into the adjacent porcelain pipe beyond the fitting holding the target.

The petcock Z3C at the upper end of the ceramic drain tube in the rear of the D-151239 power amplifier should normally be kept closed and the lower petcock Z3C kept open. In case difficulty is experienced from sludge in the cooling system, Z2C should be connected to ground and closed, and the upper petcock Z3C opened, thus grounding the center point of the main water column through the water column between the upper and lower petcocks.

The *iron* fittings at the water entrance and exit of the power amplifier are for the purpose of insuring the collection of sludge at these points. Considerable electrolysis will take place in these fittings and they should therefore be examined at proper intervals and replaced when necessary with new *iron* fittings using no pipe compound of any kind. In making such replacements great care should be used to avoid placing any strain on the porcelain piping. Otherwise, breakage is likely to result.

Note: Those fittings and the close nipple above petcock Z2C are the only iron fittings or pipe to be used in the water system.

10–9e. 405B–2 Air-Cooling System (Figure 10–16—In the 405B–2 equipment, the D–151218 power amplifier contains a motor driven blower which draws air through a spun glass filter in the back of the unit, and forces it upward through a duct in which the 343AA tubes are mounted. The heat from the tubes is thus conducted out through the top of the unit into the room. A pressure operated contactor AD1C operates to disconnect the high voltage and filament supplies to the tubes if the air pressure in the duct should fall below the minimum necessary for proper cooling.

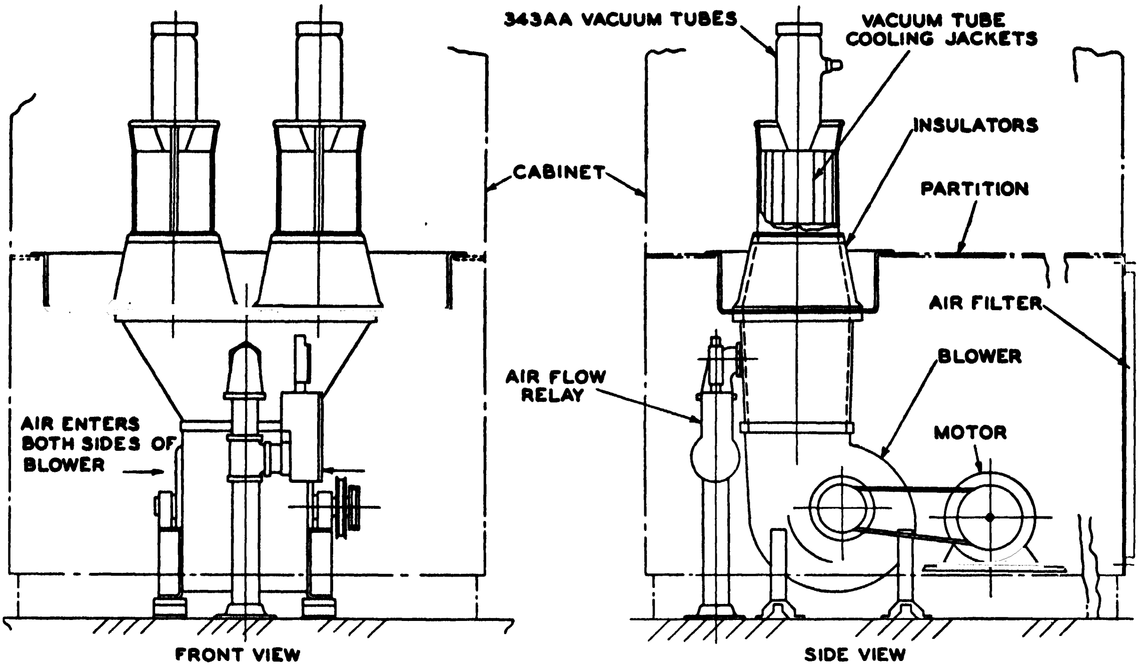


FIG. 10–16. Air cooling system (405 B-2 equipment).

The motor and blower pulleys supplied are as follows:

Two 7-inch pulleys, for blower
Two 3.8-inch pulleys, for motor
One 5.8-inch pulley, for blower
One 5-inch pulley, for motor

During the preliminary testing and adjustment, the 5.8-inch and 5-inch pulleys should be used. For regular operation these should be removed, two 7-inch pulleys installed on the blower, and the two 3.8 inch-pulleys on the motor, and two belts used, to avoid shutdown if one should break. By this arrangement, the blower is operated at a higher speed during the initial tests, which often require more than normal heat dissipation from the tubes.

10–9f. D–151215 Oscillator Amplifier (Figure 10–17)

1. *Oscillators.* The carrier frequency of the transmitter is supplied by either one of two 702A oscillators which are mounted in the slide-rail assemblies in the upper compartment of the oscillator-amplifier unit.

All connections to the oscillator units are made by means of spring contacts which engage when the units are properly inserted.

Each oscillator contains the quartz crystal Y1, the vacuum tube V1, and associated circuits, and the temperature-control circuit consisting of the heater resistance R6 and thermostat TD1.

The intermittent operation of the heater thermostat maintains the crystal at a constant temperature. Power for the heater is obtained through the transformer T7A and is supplied as soon as power is connected to the transmitter irrespective of its operation. Lamps E1A and E2A indicate when the thermostats are closed and current flows in the heater circuits.

Each oscillator is adjusted as a unit to the operating frequency and will maintain its calibration well within ± 10 cycles.

The radio-frequency output obtained from terminal 3 of each oscillator is connected to the "Oscillator" switch D5A, which permits connecting either oscillator to the grid circuit of the first amplifier tube. Plate supply for the oscillator is also connected through this switch and is obtained from a slider on resistance R62A.

2. *First Radio-Frequency Amplifier Stage.* The radio-frequency input voltage to the first amplifier tube V1A is impressed across resistance R3A. Condensers C1A and C2A provide radio-frequency paths to the cathode of V1A and to ground. The output of this stage and thus the output of the transmitter is controlled by changing the setting of the RF OUTPUT control R4A which varies a bias voltage applied to the grid of V1A through the resistances R47A and R3A. The potential drop in R4A is obtained through the REDUCED POWER ADJ. potentiometer R56A connected to the lowest slider on R61A. The plate of V1A works into the antireso-

nant circuit consisting of the inductance L1A in parallel with the variable condenser C5A which is tuned by the control PLATE CIRCUIT TUNING v1. Condenser C4A provides the radio-frequency return path to the cathode of V1A. Plate potential of V1A is supplied through the tuning coil L1A, the choke coil L2A and resistance R6A from a slider on the resistance R60A in the rectifier load circuit. Screen voltage is obtained through R5A from a slider on R60A. Condenser C3A provides a radio-frequency bypass from screen grid to cathode. Plate current of V1A is measured by the potential drop across resistance R7A and is indicated by the TEST METER when the TEST METER switch D10A is in position v1 PLATE x20. "Plate Current" as measured in this equipment indicates the total current from the tube cathode, a portion of which may flow to other elements of the tube than the plate, such as the grid and screen.

3. *Second Radio-Frequency Amplifier Stage.* The output of V1A is coupled to the grid circuit of the second amplifier tube V2A through the condenser C6A. Resistances R8A[2] and R9A provide a grid load and path for the negative bias which is obtained by the potential drop in the resistances R10A[3] and R11A, between cathode and ground. Grid current in this tube is indicated by the potential drop across R8A and is obtained with the test meter switch in position v2 GRID x5. Total space current is indicated by the potential drop in R10A and is obtained with the test meter switch in position v2 PLATE x100.

The plate of V2A works into the tuned transformer L3A. The tuning is accomplished by the adjustable condenser C10A, the control of which is designated PLATE CIRCUIT TUNING v2. The coupling of this transformer is varied by the control designated OUTPUT COUPLING v2. A tap on L3A provides a connection through the condenser C11A and terminal 51 for a radio-frequency monitoring circuit. The secondary of L3A is tuned by inductance L5A and condenser C14A. This condenser (C14A) is adjusted by the control designated OUTPUT CIRCUIT TUNING v2 and is shunted by the radio-frequency load resistance R93A.

Plate potential for V2A is obtained from the upper strap on R60A through R13A, L4A and R90A, and the primary of L3A. Screen-grid potential is supplied through R12A from the lower strap on R60A. Condensers C7A, C8A and C9A provide radio-frequency bypasses to ground.

4. *Modulating Amplifier.* Resistances R93.1A and R93.2A constitute the grid load of the modulating amplifier tubes V3A and V4A. The plate circuit consists of the anti-sing assemblies L19A, R83A, and L20A, R84A, one winding of the transformer L9A, the blocking condenser C19A, and the shunting circuit L10A, C51A and C20A. The control of C20A is designated PLATE CIRCUIT TUNING 3RD AMP. The secondary of L9A in series with the adjustable condenser C15A provides a neutralizing circuit, the control of which is designated NEUTRALIZING 3RD AMP.

A d-c fixed bias potential, which is in addition to the self-bias provided by resistors R19A and R23A, is obtained from a tap on R65A. This fixed bias is fed through audio isolating choke L7A, the secondary of L3A, L5A and to the tube grids. L8A and C12A are a resonant radio-frequency bypass circuit which presents a high impedance to the audio-frequency modulating voltages.

The modulating amplifier is modulated by varying the magnitude of its effective bias at audio frequencies according to the program transmitted. The audio modulating voltage is applied between ground and the low radio-frequency potential side of the secondary of L3A.

5. *Audio Amplifier.* The amplifier which provides the necessary audio-frequency modulating voltage has two resistance-coupled stages employing tube V6A in the first stage and tubes V7A and V8A in parallel in the second stage. The input to the first stage is the difference of two voltages, one the signal from the speech-input equipment through the input transformer T10A across resistance R27A, the other a portion of the signal fed back from the output of the transmitter, demodulated by a full-wave rectifier V9A, and applied in series with the speech input voltage, through C23A and R48A to ground. The speech-input circuit consists of the input transformer T10A, the resistance networks R73A to R82A, inclusive, and the contacts of relays S8A and S9A. The grid bias of tubes V6A, V7A and V8A is obtained by the potential drop across resistance (R30A, R38A and R42A) between each tube cathode and ground. Each tube space current is measured by the drop across meter shunts R29A, R37A and R41A that are provided in the circuits. The output circuit of V7A and V8A is connected to the grid of V3A and V4A through C35A, rotor of L3A and L5A, so that audio-frequency power is connected to the modulated amplifier C13A and R44A connected in shunt with the audio load constitute an adjustable load.

The radio-frequency rectifier tube V10A associated with its input transformer T9A and output transformer T11A furnishes a means of audio-frequency monitoring by rectifying a portion of the power amplifier output.

6. *Power-Supply Circuits.* The filaments of all vacuum and rectifier tubes in the oscillator-amplifier unit are heated by alternating current from transformers T2A, T3A, T4A and T12A. A single-phase full-wave rectifier employing mercury vapor tubes V12A, V13A, V14A and V15A with V16A as a spare supplies all screen and plate potentials.

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[2] Resistances R8A and R10A are meter shunts of negligible resistance.

[3] Resistances R8A and R10A are meter shunts of negligible resistance.

The lower potentials are obtained from sliders on the potentiometers associated with the filter circuits of the rectifier. A single-phase full-wave rectifier employing high-vacuum rectifier tube V11A supplies the fixed grid-biasing voltage for the modulated amplifier stage V3A and V4A.

7. *Preliminary Circuit Adjustment.* Before applying any power all d-c overload relays should be adjusted in accordance with Table 9 and protective gaps in accordance with Table 10. (Tables 1 to 12 appear at the end of this section, pp. 394–396.)

With the POWER and PLATE RECTIFIER controls in the OFF position place vacuum tubes in their respective sockets according to Table 12.

Turn the POWER switch ON and allow sufficient time for all vacuum-tube filaments to become properly heated. For normal operation the heating time is automatically taken care of by delay circuits. However, the filaments of new mercury-vapor tubes should be heated at least fifteen minutes before the high voltage is applied. This preheating removes any particles of mercury adhering to the sides or elements of the tubes after shipment or handling, thus minimizing the possibility of flashovers. If, after such preheating, an arc-over occurs when the high voltage is applied, the high voltage should be removed, and the heating period extended an additional fifteen minutes. With the OSCILLATOR-AMPLIFIER CONTROL switch, D11F, of the control unit in the TEST position there is no automatic delay for the protection of the rectifier tubes. *Under these conditions a filament heating time of at least fifteen seconds should be allowed before applying the plate voltage.*

After inserting the 702A oscillators and applying the heater power by placing the OSC. HEATER switch (D1A) in the "ON" position, the indicator lights will be on continuously until the unit has reached the normal operating temperature (approximately 60 degrees Centigrade) as indicated by the thermometer. When starting from normal room temperature this time should be approximately one hour. Thereafter the lights should be alternately "ON" and "OFF" for periods of about thirty seconds, the exact time depending upon the ambient temperature.

The resistance value of the rectifier surge limiting resistor, R68A, should be checked and adjusted, if necessary, for a value of 8 ohms. The voltage taps, which are provided for the lower screen and plate voltages, should be checked before applying power to the unit. This can be done by removing the ground leads from R61A and R62A and the interconnecting lead between the grounded ends of these resistors. The approximate values of the resistances are shown in Table 4.

Make preliminary adjustments of the radio frequency circuits according to Table 3.

In the following instructions for adjusting the oscillator amplifier, reference to controls will be made in accordance with the title provided on the controls. The following table shows the title of the control and the corresponding designation number of the apparatus with which it is associated. Other apparatus will be referred to in accordance with its designation number.

8. *Outside Controls*

Apparatus Designation Number	*Control Title*
C5A	Plate Circuit Tuning V1
C10A	Plate Circuit Tuning V2
C14A	Output Circuit Tuning V2
C15A	Neutralizing 3rd Amp.
C20A	Plate Circuit Tuning 3rd Amp.
D3A	Power ON-OFF
D4A	Plate Rectifier ON-OFF
D5A	Oscillator No. 1–No. 2
D10A	Test Meter (Rotary Switch)
D11A	Overload Reset
L3A	Output Coupling V2
R4A	RF Output

9. *Inside Controls*

C12A	RF By-pass Tuning
D1A	Osc. Heater ON-OFF
D2A	Power Supply Cct. Bkr. IN-OUT
R48A	Feedback Adj.
R56A	Reduced Power Adj.

When circuit currents are to be read on the TEST METER, current readings are obtained by multiplying or dividing the actual meter indication by the factor indicated by the setting of the TEST METER switch.

The apparatus designation number and the corresponding title of meters on the oscillator-amplifier unit are as follows:

Apparatus Designation Number	*Title of Meter*
M2A	Test Meter
M3A	Plate Rectifier
M4A	Third Amp. Plate Current
M5A	Third Amp. Plate Circuit
M7A	Antenna Current

10. *First Radio-Frequency Amplifier Tuning.* Resonance is obtained in all plate circuits by an adjustment for minimum d-c plate current of the tube whose tuned output circuit is being adjusted. In tuning any of the radio-frequency circuits care should be taken that no circuit is tuned to the second harmonic of the fundamental frequency. Should two points of resonance be found with coil setting specified, the one at which the capacitance of the variable condenser is maximum is the correct adjustment. This will correspond to the point of higher dial reading and higher output current.

Before applying plate voltage open links D6A, D7A and D17A.

> *Caution:* When links D6A and D7A are open and the plate rectifier switch is opened, sufficient time must be allowed for the high-voltage condensers to discharge before working on any apparatus. The condition of the charge may be noted by observing the PLATE RECTIFIER meter.

If switch D11F is in the test position, no adjustment of the apparatus in the oscillator-amplifier should be made without first placing the PLATE RECTIFIER switch in the OFF position and also opening one of the front doors of the unit to remove the bias potential.

Place the PLATE RECTIFIER switch in the ON position and the TEST METER switch on the v1 PLATE x20 position. With the RF OUTPUT control set at about 80 adjust the PLATE CIRCUIT TUNING v1 control until the TEST METER indicates a minimum, or until the TEST METER indicates a maximum when turned to the position v2 GRID x5.

11. *Second Radio-Frequency Amplifier Tuning.* With the OUTPUT COUPLING v2 control set at zero[4] and the TEST METER switch on the v2 PLATE x100 position adjust the PLATE CIRCUIT TUNING v2 control until the TEST METER indicates a minimum. With the OUTPUT COUPLING v2 control at approximately 10 adjust the OUTPUT CIRCUIT TUNING v2 control until the TEST METER indicates a maximum.

12. *RF By-pass Tuning.* Remove plate power from the unit by placing the PLATE RECTIFIER switch in the OFF position. Place link switch D17A in position 1–4. This connects the radio-frequency rectifier circuit containing vacuum tubes V9A and V10A to the radio frequency by-pass circuit comprising C12A and L8A through condenser C36A.

Place the TEST METER switch in either the v9 PLATE x20 or the v10 PLATE x20 position. Apply plate voltage by placing the PLATE RECTIFIER switch in the ON position. Increase the OUTPUT COUPLING v2 until a substantial indication is obtained on the TEST METER. Adjust RF BY-PASS TUNING until the TEST METER indicates minimum current. Increase OUTPUT COUPLING v2 and readjust RF BY-PASS TUNING until it is certain that the best adjustment has been obtained.

This completes the preliminary adjustments of the second amplifier plate and output circuits. Place the PLATE RECTIFIER switch in the OFF position and set the RF OUTPUT control on zero before proceeding with the neutralization of the third amplifier.

13. *Third RF Amplifier Neutralization.* Disconnect the lead between terminal 62 of Unit A and terminal 60 of Unit C. Connect the radio-frequency rectifiers V9A and V10A in the tank circuit of the third radio-frequency amplifier V3A and V4A, by connecting link switch D17A in position 1–3. Check that D6A and D7A are open. Adjust the tap on L10A which is associated with D17A for a number of turns above ground equal to about 15 percent of the total active turns. Set the TEST METER switch on v10 PLATE x20. Close the PLATE RECTIFIER switch, set RF OUTPUT control at 100, and adjust PLATE CIRCUIT TUNING 3RD AMP. control until an indication of resonance in the 3rd amp. plate circuit is indicated by a maximum in the TEST METER current. An adjustment of the active turns of L10A and auxiliary fixed condensers C51.1A to C51.3A may be necessary to obtain the resonant condition. Use the RF OUTPUT control if necessary to limit the TEST METER reading to 5 ma.

Adjust the NEUTRALIZING 3RD AMP. control until the TEST METER indicates a minimum, meanwhile increasing the RF OUTPUT control to obtain a satisfactory reading on the TEST METER. Continue this adjusting until a minimum indication is obtained on the TEST METER with the RF OUTPUT control at a maximum.

Next, readjust PLATE CIRCUIT TUNING v2, OUTPUT CIRCUIT TUNING v2, PLATE CIRCUIT TUNING 3RD AMP. and OUTPUT COUPLING v2 for a maximum indication on the TEST METER. Then readjust the NEUTRALIZING 3RD AMP. control until the TEST CURRENT meter indicates a minimum. This completes the neutralizing procedure for the third amplifier. Open the PLATE RECTIFIER switch and clamp link D17A in an open position. Replace the connection between terminal 62 of Unit A and terminal 60 of Unit C. Link D17A should be connected in position 1–2 only after the entire transmitter has been tuned and feedback is to be applied.

14. *Third RF Amplifier Tuning.* Close links D6A and D7A and set the RF OUTPUT control at zero. Adjust L13C, L14C, and C12C (INTER-GRID COUPLING control) which are in the grid circuit of Unit C. (Table 5 shows power amplifier coil and condenser adjustments for various operating frequencies.) Close switch D7C of Unit C. The tube filaments of the latter unit should be off during these adjustments.

Close the PLATE RECTIFIER switch and increase the RF OUTPUT control until the GRID LOAD CURRENT meter (M4C) of Unit C indicates between 65 and 100 milliamperes. Check the tuning of the third radio-frequency amplifier by adjusting PLATE CIRCUIT TUNING 3RD AMP. for a minimum plate current as indicated by the 3RD AMP. PLATE CURRENT meter. Increase the RF OUTPUT control until GRID LOAD CURRENT meter of Unit C indicates a load current of between 70 and 110 ma, with the grid load resistor R5C set for 600 ohms (all units in circuit).

Observe the phase relation of the two grid voltages of V1C and V2C of Unit C on a cathode-ray oscilloscope whose two pairs of plates are connected respectively to the GRID v2 and GRID v1 jacks. A 90° relation is indicated by an elliptical pattern with the axes of the ellipse horizontal and vertical. The phase may be varied by adjusting the GRID CIRCUIT TUNING control (C11C). For proper operation a 90° phase relationship must exist between the grid voltages of V1C and V2C. If a 90° relation is not obtained at any setting of GRID CIRCUIT TUNING, an adjustment of the turns of L13C is required. If the best tuning is obtained with the GRID CIRCUIT TUNING control at minimum, the number of turns of L13C should be reduced; if the best tuning is obtained with the GRID CIRCUIT TUNING control at a maximum, the number of turns of L13C should be increased. Inspection of the cathode-ray pattern is ordinarily facilitated if the sampling coils are so adjusted that the vertical deflection is somewhat greater than the horizontal deflection. Deflection is varied by adjusting the active turns on sampling coils L7C and L8C.

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[4] A careful check should be made to insure that when the "Output Coupling V2" control is set at zero the coupling is really a minimum.

After a 90° phase relationship has been satisfactorily obtained between the grid voltages of V1C and V2C, disconnect the coil L10A from circuit by opening the slider on the high end of the coil and meter M5A 3RD AMP. PLATE CIRCUIT will of course no longer indicate. Readjust the PLATE CIRCUIT TUNING 3RD AMP. of Unit A for minimum plate current as indicated by the 3RD AMP. PLATE CURRENT meter.

After the above adjustments have been made the various circuit voltages should be checked with Table 4.

15. *Final Adjustment of the Second RF Amplifier.* After the circuits of Unit A have been tuned the following final adjustments should be made to obtain vernier action with the RF OUTPUT CONTROL. With the RF OUTPUT control at 85 and the OUTPUT COUPLING v2 control at zero set the TEST METER switch on the v2 PLATE x100 position and place the PLATE RECTIFIER switch in the ON position. Check the adjustment of the PLATE CIRCUIT TUNING v2 control for a minimum plate current as indicated by the TEST METER. Turn the OUTPUT COUPLING v2 control until the plate current of V2, as indicated by the TEST METER, is increased about ten per cent. Check the adjustment of the OUTPUT CIRCUIT TUNING v2 control for a maximum of V2 plate current as indicated on the TEST METER. It is important that the PLATE CIRCUIT TUNING v2 and OUTPUT CIRCUIT TUNING v2 control settings are not changed when making the following adjustments. Place the PLATE RECTIFIER switch in the OFF position. With the RF OUTPUT control set at 85 and the OUTPUT COUPLING v2 at 100, place the PLATE RECTIFIER switch in the ON position. Turn the OUTPUT COUPLING v2 control counter-clockwise until the GRID LOAD CURRENT meter of the Unit A indicates 70–110 ma. Thereafter, the rf output should be controlled by means of the RF OUTPUT control.

After the entire 5-kw transmitter has been tuned in accordance with the remaining instructions turn the OUTPUT COUPLING v2 control to 100 and set the RF OUTPUT control at 85. With all plate voltages on, turn the OUTPUT COUPLING v2 control counter-clockwise until the normal carrier output current is obtained. The adjustment of antenna or output current should thereafter be made by means of the RF OUTPUT control.

If any tendency toward parasitic oscillations exists after the above adjustments are completed, the neutralizing of the third radio-frequency amplifier should be checked. This should be done without changing any of the other radio-frequency adjustments.

16. *Adjustment of Sliders on R61A.* The sliders on R61A provide the potentials for the RF OUTPUT control potentiometer. With this control at zero and all plate voltages on, the rf output should be approximately zero. Raising the upper or second slider on R61A will reduce the output, while lowering it will increase the output. With this slider adjusted to give approximately zero output, set the RF OUTPUT control at 85 and the TEST METER switch on the v2 GRID x5 position. If the grid current is not within the specified limits of 0 to 4 milliamperes it will be necessary to adjust the lower or first slider on R61A. Raising this slider increases the grid current as well as the RF output of the transmitter. After the proper position of the lower slider has been determined, check the position of the upper slider for zero radio frequency output when the RF OUTPUT control is set at 20. When the proper adjustment of the sliders is obtained set the RF OUTPUT control at 85 and readjust the OUTPUT COUPLING v2 control until normal carrier output is obtained. The final position of the OUTPUT COUPLING v2 control should be such that turning this control counter-clockwise produces an increase in antenna or output current.

Routine tests should be made with the RF OUTPUT control to determine that carrier cut-off definitely takes place when this control is between the limits of 0 and 20.

17. *Adjustment of Feedback and Associated Circuits.* After the entire transmitter has been tuned, as covered in the balance of this instruction book, adjustments of the feedback circuit and associated circuits should be made. To measure the feedback, remove the feedback rectifier tube V9A of the oscillator amplifier, close link switch D17A in the 1–2 position, and modulate the transmitter with a single frequency of 400 cycles, noting the required input level for 100-percent modulation. When the tube is replaced the audio input level for 100-percent modulation should be approximately 0 db. The difference of the two input levels is then the value of feedback.

The following procedure should be followed to obtain the required value of stable feedback. With feedback rectifier tube V9A removed from its socket and the transmitter delivering full power, adjust R44A to approximately mid-position, and adjust R103A for a nonsinging condition. Singing can readily be observed by means of a cathode ray oscilloscope using the sweep circuit and the vertical plates plugged into J2C, especially if the transmitter is modulated with a low frequency, such as 50 cycles. A singing condition will usually be ob-

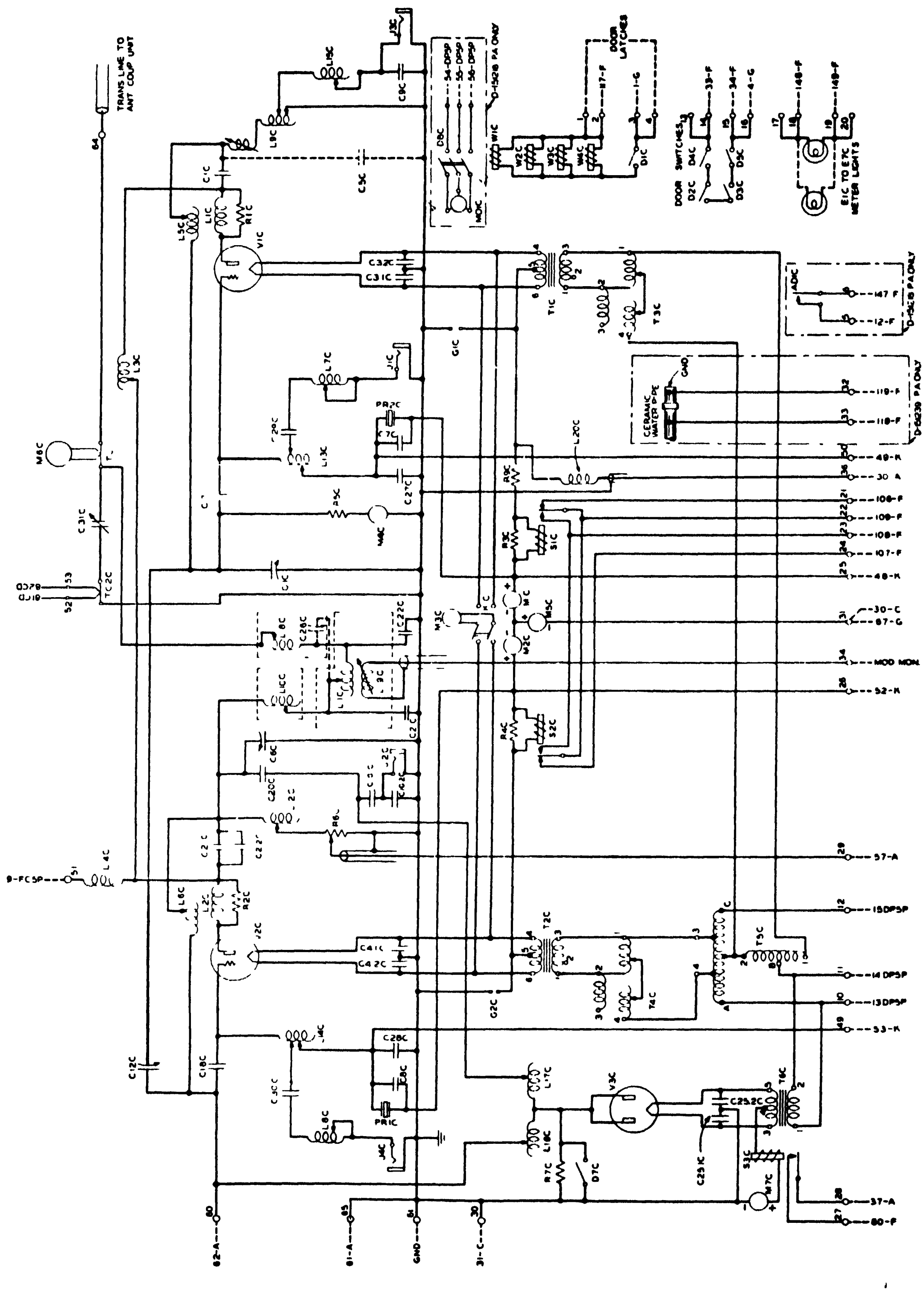

Fig. 10-18. Unit C— D-151239 (or D-151218) power amplifier.

served at a low value and a high value of resistance in R103A, and a mid-point position should be selected. Insert V9A and determine the maximum setting of R48A FEEDBACK ADJ. which can be used without singing. A slight readjustment of R44A may enable a higher value of R48A to be used. Then decrease the FEEDBACK ADJ. control the equivalent of 2 or 3 db. The final value of feedback should be about 20 db.

Whenever major adjustments of the radio-frequency circuits of the transmitter are to be made, the feedback should be removed by opening link D17A or removing tube V9A.

18. *Audio Monitoring Rectifier.* The radio-frequency rectifier tube V10A and its associated circuit furnish a source of audio monitoring output from the transmitter. The control desk "monitor" key connects the input of the component 124 type amplifier either to this output or to the transmitter audio input.

The direct-current component of this rectifier is used to operate relay S8A which in turn closes the audio input circuit when the carrier output is normal. Reducing the carrier to zero either manually or by the protective circuits that are provided removes all the feedback voltage. If the audio input were not removed under these conditions the audio system would be overloaded by an amount equal to the normal value of feedback.

10–9g. D–151239 (or D–151218) Power Amplifier Unit (Figure 10–18)

1. *Circuit Description.* This power amplifier employs two vacuum tubes V1C and V2C connected in a high-efficiency circuit, driven by the output of Unit A and arranged for connection to the antenna system by a coaxial transmission line or other coupling device having an impedance of 50 to 80 ohms.

The radio-frequency input is applied directly to the grid of V2C but reaches the grid of V1C through the intergrid coupling condenser C12C. C17C and C18C are grid blocking condensers. The current in grid load resistors R5C is indicated by ammeter M4C. The grid phase-shifting circuit is completed by coil L13C and condenser C11C. The sampling circuits (C29C–L7C and C30C–L8C) permit checking the phases of the grid voltages on the tubes by connecting a cathode-ray oscilloscope at jacks J1C and J4C.

Coil L5C neutralizes the non-linear amplifier tube V1C by anti-resonating its internal capacity. Neutralization of tube V2C is effected in a similar manner by L6C.

The tuned output circuit of V1C consists of coil L9C and the circuit capacity to ground. The sampling circuit L15C–C9C permits checking the phase of the output voltage of V1C at jack J3C. The output circuit of V1C is coupled to that of V2C by means of coil L3C which also serves to carry the d-c plate current from V2C to V1C.

The tuned output circuit of V2C consists of variable condenser C6C (to which is added a fixed condenser C20C) and the V2C plate coil L10C. The phase of the output voltage of V2C may be checked at jack J2C, connected across condenser C10.2C. Coil L12C and resistance R6C provide a small part of the output of the amplifier at terminal 29, to be used for stabilized feedback.

Between the V2C plate coil L10C and the line there is connected a radio-frequency harmonic filter consisting of coils L11C and L18C, and condensers C21C, C22C and C26C. The current fed into the transmission line is indicated on meter M6C connected to thermocouple TC1C. As supplied, condenser C26C is not connected. This condenser is to be used only in case unusual suppression of some particular radio-frequency harmonic is necessary. In that case C26C is connected in parallel with a portion of L11C and tuned to parallel resonance at the particular harmonic frequency it is desired to suppress, making proper readjustment of L11C to maintain the tuning at the fundamental frequency.

Connected across the input and output circuits of tube V2C are two coils L16C and L17C associated with a protective device which also serves as an overall tuning indicator for the amplifier. The other elements comprised in this protective device are the rectifier tube V3C with its filament transformer T6C and filament by-pass condenser C25C, the shunting resistance R7C for this tube with a disabling switch D7C, a relay S3C, and a d-c milliammeter M7C for reading the rectified output of tube V1C.

The high-voltage plate supply is fed to the power amplifier through plate choke coil L4C. The two grid-bias supplies are fed to the tubes through grid coil L13C and L14C, the higher bias being employed for V2C. The grid-bias voltage for V1C is filtered by C7C which is protected against abnormal voltages by thyrite protector PR2C. The corresponding grid-bias equipment for V2C consists of C8C and PR1C.

The plate currents of the individual tubes are indicated on meters M1C and M2C and the total plate current on meter M5C. The overload relays S1C and S2C are equipped with shunts, designated R3C and R4C.

An anti-sing assembly consisting of R1C–L1C is connected in the plate lead of V1C. A similar circuit consisting of R2C–L2C is connected in the plate lead of V2C.

Plate blocking condenser C1C is used for tube V1C, and blocking condenser C2C for V2C, C3C and C4C are filament by-pass condensers.

The individual filament voltages on the tubes are indicated by meter M3C connected to key K1C and adjusted by Transtats T3C and T4C.

Variable condenser C31C serves to control the output of thermocuple TC2C, which energizes control desk meter M3CD.

2. *Circuit Adjustment*

Note: Before proceeding with the adjustment of the power amplifier it is necessary that the radio-frequency transmission line be connected to the antenna system through suitable coupling equipment, adjusted to terminate the line in its characteristic impedance. No information on this adjustment is included herein.

3. *Preliminary.* In the following instructions for adjusting the power amplifier unit, reference to controls will be made in accordance with the title provided on the controls. The following table shows the title of the control and the corresponding designation number of the apparatus with which it is associated. Other apparatus will be referred to in accordance with its circuit designation number.

Apparatus Designation Number	*Control Title*	
C6C	Plate Circuit Tuning V2	
C11C	Grid Circuit Tuning	
C12C	Inter-Grid Coupling	
C15C	Neutralizing V1	
C16C	Neutralizing V2	
L9C	Plate Circuit Tuning V1	
J1C	Grid V1	Oscilloscope
J2C	Plate V2	
J3C	Plate V1	
J4C	Grid V2	
D1C	Door Release	
K1C	Filament Voltage V1 + V2	
T3C	Filament Voltage V1	
T4C	Filament Voltage 2	

The apparatus designation number and the corresponding title of meters on the power amplifier unit are as follows:

Apparatus Designation Number	*Title of Meter*
M1C	Plate current V1 Amperes d-c
M2C	Plate Current V2 Amperes d-c
M3C	Filament Voltage Volts a-c
M4C	Grid Load Current Milliamperes r-f
M5C	Total Plate Current Amperes d-c
M6C	Transmission Line Current Amperes r-f
M7C	Protective Circuit Milliamperes d-c

With all power removed from the equipment insert the vacuum tubes in their sockets according to Table 12. Place RECT. FIL. and 230 VOLT SUPPLY switches in the power distribution cabinet, and the RECTIFIER FILAMENTS switch D1F in the control unit in the ON position and allow sufficient time for the rectifier tube filaments to become heated. For normal operation the heating time is automatically taken care of by delay circuits. However, the filaments of new mercury vapor tubes should be heated at least 15 minutes before the high voltage is applied. This preheating removes any particles of mercury adhering to the sides or elements of the tubes after shipment or handling, thus minimizing the possibility of flashovers.

Place the OSCILLATOR AMPLIFIER CONTROL switch (D11F) in the OPERATE position and the reduced power switch (D9F) in the FULL POWER position. Make preliminary adjustments of the radio-frequency circuits according to Table 5. Adjust the FILAMENT VOLTAGE V1 and FILAMENT VOLTAGE V2 controls to the extreme counter-clockwise direction.

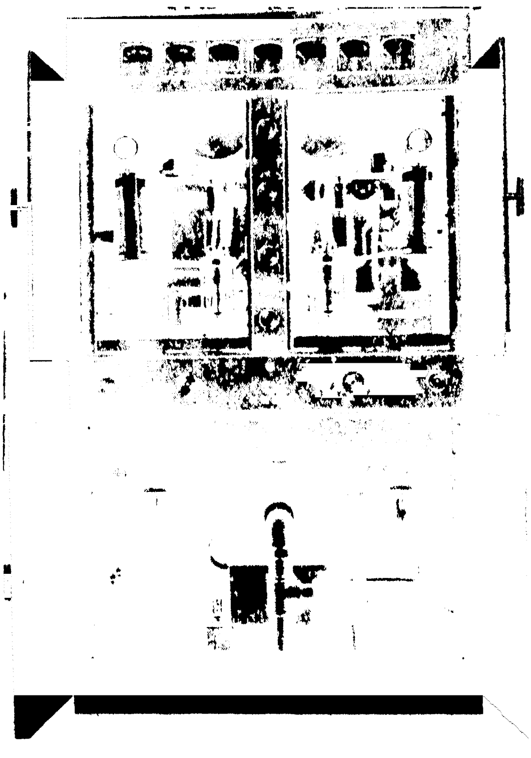

FIG. 10–19. Front view of the power amplifier unit of the Western Electric 405B-2 5-kw radio broadcast transmitter with the doors open.

4. *Tuning of Output Circuit*

Note: All output circuit adjustments should be made by measuring impedances as outlined below at the station carrier frequency with a radio-frequency bridge.

5. *Adjustment of Harmonic Filter.* The first step in tuning the output circuit of the power amplifier is the adjustment of the radio-frequency harmonic filter. The fixed condensers in the harmonic filter are supplied to correspond to the station's frequency, and adjustments must be made on L11C and L18C.

L18C and L11C are adjusted by measuring the impedance across C21C with L10C disconnected from L11C and C21C, and a General Radio decade resistance box set for 65 ohms (or an equivalent resistor) connected from terminal 64 to ground. The lead to the transmission line or antenna from terminal 64 must also be disconnected.

Coils L18C and L11C should be adjusted to give a series input resistance as measured by the bridge (arranged for measuring series components of grounded impedances) across condenser C21C of 65 to 90 ohms. The reactive component is not important, but should not in general exceed 100 ohms. Any reactive component that results merely requires either a corresponding increase or decrease in the turns of L10C that will be required to tune the plate circuit of V2C. In the adjustment of L11C and L18C it will be found that in general decreasing the number of turns in L11C decreases the resistance measured across C21C, and decreasing the turns in L18C increases this resistance. The number of turns in each of these coils should be kept as large as possible and still obtain a value of resistance between 65 and 90 ohms, since the radio-frequency harmonic suppression decreases with a decrease in turns. Upon completion of these measurements and adjustments restore the connection between coil L10C and condenser C21C.

6. *Adjustment of Load (Plate Circuit) Impedances.* This consists in selecting the proper tap on coil L10C to give the desired load impedance, approximately 2700 ohms, for the combined output of both tubes, and then the proper tap on coil L3C to give the desired load impedance, approximately 10,800 ohms, for tube V1C when this tube is supplying the smaller carrier output without appreciable assistance from tube V2C.

In the 405A-2 equipment, the adjustment of load impedances should be carried out with the water system filled and the cooling system operating, so that the resistances of the water columns will be included in the measurements.

By means of the radio-frequency bridge, arranged to measure parallel components of grounded impedances, and with the tube socket of V1C temporarily grounded, measure the parallel resistance between the tube socket of V2C and ground at the carrier frequency. This parallel resistance is controlled entirely by the reactance of coil L10C and by the introduced resistance as determined by the adjustment of coils L11C and L18C as previously described. Coil L10C should be adjusted to give a value for the plate-to-ground resistance of 2700 ± 100 ohms. Increasing the number of turns on L10C increases the parallel resistance and vice versa. If it is impossible to secure a value of parallel resistance within the above limits by adjusting L10C, a change in the introduced resistance by readjustment of L11C and L18C must be made. Increasing the introduced resistance lowers the parallel resistance and vice versa.

Upon completion of the adjustment of coil L10C, condenser C6C PLATE CIRCUIT TUNING V2 should then be adjusted until the impedance is purely resistive. The parallel resistance will not change when condenser C6C is adjusted.

Next remove the temporary ground from the plate of the tube V1C and connect the bridge to measure the parallel impedance between the socket of tube V1C and ground. The parallel resistance at this point is controlled entirely by the reactance of coil L3C, which should now be adjusted to give a value of 10,800 ± 400 ohms for this resistance. In case it is necessary to readjust L3C by more than four or five turns, the previously described adjustment of C6C should be repeated to secure zero reactance (with the plate of V1C again grounded and measuring from the plate of V2C to ground), and then recheck the parallel resistance from the plate of V1C to ground, making any further slight readjustment of L3C that may be required to secure the parallel resistance value of 10,800 ± 400 ohms. Then adjust the value of coil L9C by changing turns and with the fine adjustment PLATE CIRCUIT TUNING V1 until the parallel impedance is purely resistive. Adjustment of coil L9C has no effect upon the parallel resistance.

7. *Tuning of Grid Circuit.* With the grid circuit tuned, the PLATE CIRCUIT TUNING control on the oscillator amplifier unit should be readjusted to give minimum plate current in that stage. This may necessitate a readjustment of the turns in L14C but this will not affect the grid phase displacement.

The power amplifier is now ready for neutralizing and final tuning adjustments.

8. *Neutralizing of Power Amplifier.* Neutralization of the power amplifier is accomplished by using a cathode-ray oscilloscope as a voltage indicator, and adjusting the neutralizing controls for a minimum deflection on the cathode-ray tube. The plate of the tube not being neutralized should be grounded with a temporary connection. The clips on neutralizing coils L5C and L6C should be set to include in circuit approximately ⅔ the total turns of each coil.

To neutralize tube V2C, disconnect the rear terminal of the coil L8C (terminal 60) from the busses normally connected there, and keeping the removed busses connected together. Connect this rear terminal of L8C to the plate of V2C using a temporary connector, taking care to keep this temporary connector several inches away from coil L14C to avoid stray coupling. Plug the lead from the vertical plates of the cathode-ray tube in jack J4C. Operate the transmitter *with no plate voltage* on the power amplifier and adjust the tap location on coil L6C for a minimum indication on the cathode-ray tube. This completes the neutralizing of V2C.

To neutralize tube V1C transfer the temporary connection from the rear terminal of L8C to the plate of V1C, again taking care to keep this lead away from coils L14C, and removing the grounding clip from the plate of V1C and using it to ground the plate of V2C. Repeat the procedure outlined for neutralizing tube V2C, this time adjusting L5C for a minimum indication on the cathode ray. This completes the neutralizing of the power amplifier. Upon completion remove the temporary connectors and reconnect the rear terminal of L8C to the busses.

Note: If a vacuum tube voltmeter is available the power amplifier may be neutralized by connecting the voltmeter to indicate the radio frequency voltage from plate of the tube to ground. Operating the transmitter *with no plate voltage on the power amplifier,* adjust the associated neutralizing coil for a minimum indication, as outlined above. The plate of the tube not being neutralized should be grounded, as indicated.

9. *Final Tuning of Power Amplifier.* Place the entire transmitter in operation. Apply excitation until the PLATE CURRENT v1 meter reads about 0.1 amp. Check the 90° grid-circuit relation, making such minor readjustment of the GRID-CIRCUIT TUNING (C11C) as necessary to secure the 90° relation. Next observe the phase relation of the plate potentials of the two tubes, using the PLATE v1 and PLATE v2 jacks increasing the RF OUTPUT (R4A) if necessary to secure adequate deflection on the cathode ray. Adjust condenser C6C by means of the PLATE CIRCUIT TUNING v2 control for a 90° phase difference. This is the only control which affects the relative phases of the plate potentials. Check the adjustment of the PLATE CIRCUIT TUNING 3RD AMP. control on the oscillator amplifier for minimum plate current of that stage. A readjustment of this control may be necessary with the power amplifier in operation.

Coil L9C is next readjusted by means of the PLATE CIRCUIT TUNING v1 control until a cathode-ray oscilloscope connected to the GRID v1 and PLATE v1 jacks shows a straight-line pattern, indicating a pure phase reversal in the tube, i.e., the plate load impedance is a pure resistance. This should also correspond with minimum V1C plate current.

With the two grid potentials 90° apart and the two plate potentials 90° apart, and with a pure phase reversal in tube V1C, the grid and plate potentials of tube V2C should now be 180° apart. This may be checked with the cathode-ray oscillograph using the GRID v2 and PLATE v2 jacks.

Next increase the excitation until, with 12,000 volts plate potential, the output of the transmitter is the required 5 kilowatts, as indicated by the antenna-current meter in the antenna-coupling unit. The number of active turns in L7C and L8C should now be adjusted to give proper deflections on the cathode-ray oscilloscope. This readjustment may necessitate a slight retuning of the grid circuits to retain the proper grid phasing relations. At this time if the antenna is of the series-excited type, the relation of TRANSMISSION LINE CURRENT, as read on meter M6C, to actual antenna current may be determined, and the adjustment of the pick-up circuit for remote indication of antenna current, if used, may be made to obtain the proper reading on M7A ANTENNA CURRENT. In the case of a shunt-excited antenna, meter M6C will read ANTENNA CURRENT and should indicate the same as the antenna meter in the antenna coupling unit.

At the 5-kw output check the phase adjustments and observe the plate currents of the tubes. The plate current of V1C should be about 0.6 amp, V2C should be between 0.09 and 0.11 amp, and the total plate current should be between 0.68 and 0.70 amp. The plate current of tube V2C may be increased or decreased by changing the setting of the INTER-GRID COUPLING control. This requires a slight readjustment of the GRID CIRCUIT TUNING control to maintain the 90° phase relation.

Note: The above value of total plate current assumes antenna power determination by the direct method of measurement. If, to meet an emergency condition, the power is to be determined by indirect measurement, using an efficiency factor of 0.65, the drive may be reduced to make the total plate current 0.63 to 0.65 amp, in which case the output will be correspondingly reduced.

If the plate current of tube V2C at 5 kw output cannot be made high enough by adjustment of the INTER-GRID COUPLING control, lowering the grid load resistance R5C by short-circuiting one or two of the resistance units will have the desired effect. This resistance must not be reduced lower than 3600 ohms. (Three units in circuit, 2 shorted out.)

It is also possible to adjust the distribution of load between the tubes at the carrier output by varying the bias-supply voltage to one tube or the other by means of the sliders on the bias rectifier bleeder resistors. It is usually found, however, that best results are obtained with the specified biases of approximately 300 and 450 volts on V1C and V2C respectively.

With the required carrier output, observe the plate current of the modulated amplifier stage (M4A in Unit A). This should be between 150 and 200 milliamperes total for the two tubes. It may be adjusted to within these limits by changing the adjustment of the INTER-GRID COUPLING CONDENSER C12C, and readjusting the GRID TUNING CONDENSER C11C to again secure proper phase relationship on V1C and V2C grids. For each new adjustment on C12C, condenser C20A should be readjusted to minimum plate current. If more than a minor adjustment in C12C is made, it will be necessary to readjust the bias on V2C to maintain the plate current of that tube within the specified limits.

Place link D17A of unit A in the 1–2 position and observe the feedback current as indicated on the v9 PLATE setting of the test meter in the oscillator amplifier unit. The taps on the feedback coil L12C should be adjusted to give a feedback current, at the full carrier output, 8 ± 2 ma.

The further adjustment of the feedback is described under "Adjustment of Feedback and Associated Circuits," and reference should be made thereto at this time.

10. *Adjustment of Radio-Frequency Protective Circuit.* The adjustment of this circuit consists in choosing proper taps on coils L16C and L17C to obtain a null indication on meter M7C PROTECTIVE CIRCUIT when the power amplifier is tuned.

Open switch D7C. Choose taps arbitrarily on L16C and L17C. Place the entire transmitter in operation. At the full carrier output check the phase relations with the cathode-ray oscilloscope. Observe the reading of M7C PROTECTIVE CIRCUIT and note the change in this reading as condenser C6C PLATE CIRCUIT TUNING V2 is adjusted above and below the tuning point determined from the oscilloscope. At a reading of between 7 and 10 ma the protective circuit should operate to remove and reapply the excitation at intervals, provided switch D12F PROTECTIVE CIRCUIT on the control unit is in the ON position. Note the minimum reading obtained on meter M7C. Remove plate voltage and bias and choose a new tap on either L16C or L17C and repeat the above observations. The taps eventually chosen should give a minimum reading on meter M7C of not more than 3 ma at 5 kw output, and the setting of condenser C6C for this minimum should be in close agreement with the cathode ray indication of 90° phase displacement between V1C and V2C plate voltages.

Later, when modulation is applied, meter M7C should be observed again. If, with modulation applied, the reading should increase to a value likely to cause undesired operation of the protective circuit, the sensitivity of the device may be reduced by using more of the turns on L16C and L17C, keeping the ratio approximately unchanged.

11. *Modulating the Transmitter.* With the final stage adjusted to the proper operating conditions at the unmodulated carrier output, it is necessary next to observe the operation with modulation applied.

For ideal distortionless operation with no carrier shift the antenna current should rise 22.5 percent at 100-percent modulation. In transmitters not employing negative feedback, a failure of the antenna current to rise to this extent ordinarily indicates distortion in the modulated wave. With the distortion removed by feedback, the only result of such "carrier shift" is a slight decrease in transmitted signal; for example, if the antenna current rises only 15.5 percent, the loss in transmitted signal with a distortionless wave is 0.5 db. The tendency for carrier shift to occur depends on local conditions, such as instantaneous line regulation, as well as on the adjustment of the transmitter.

This equipment is designed to permit 100-percent modulation with no carrier shift, provided the line-voltage regulation is such that the plate voltage on the power amplifier does not change more than 2 percent between the modulated and unmodulated condition.

At the time of installation the grid-bias voltages are adjusted for proper performance, and should not be changed. As the power amplifier tubes age it may be necessary to increase the filament voltage to maintain constant emission for each tube. The need for such increase in filament voltage will be indicated by the failure of the antenna current to give the proper (22½ percent) increase with 100-percent single-tone modulation at the normal speech-input level. To determine which tube should have additional voltage, modulate the transmitter 100 percent with tone, raise the filament voltage of one of the water-cooled tubes, and note whether the antenna current increases. If it does not, that tube requires no increase, and the voltage should be restored to its previous value. The other tube should be similarly tested. If filament voltage increase does not correct the failure of the antenna current to increase 22½ percent with 100-percent single tone modulation, a check of the bias voltages and plate-circuit tuning should be made to determine that no changes in these circuits have occurred. The indication of the protective circuit meter furnishes a check on the condition of the output circuits, and if the reading of this meter at carrier and under modulating conditions has not changed from the values observed at the time of installation it may be assumed that the difficulty is not due to circuit tuning changes.

After the power amplifier is adjusted condenser C31C should be set so that control desk meter M3CD agrees with meter M6C at full output power.

10-9h. Starting the Transmitter

1. *Preliminary.* Assuming that the transmitter is to be operated from the control desk, the transmitter control switches on the control unit and their corresponding multiples in the control desk, should be as follows:

Designation	Control Unit Switch-Position		Control Desk Switch-Position	
Osc. Ampl. Fil.	D10F	ON	D6CD	OFF
Rect.-Fil.	D1F	ON	D7CD	OFF
Ampl. V.T. Cooling	D2F	ON	D8CD	OFF
Ampl. Fil.	D3F	ON	D9CD	OFF
Osc. Ampl. Plate	D5F	ON	D10CD	OFF
HV Rect.	D4F	ON	D11CD	OFF
Power Change	D9F	FULL	D12CD	FULL

To start the transmitter, all the manual circuit breakers in the power-distribution unit should be thrown to ON and the OSCILLATOR AMPLIFIER CONTROL switch (D11F) should be in the OPERATE position. Check the voltage of the three phases of the power supply by means of the POWER SUPPLY meter

(M1F) and POWER-SUPPLY VOLTMETER switch (D6F). Each phase should be approximately 230 volts. Throw the A-C CONTROL CIRCUIT switch (D53F) and the D-C CONTROL CIRCUIT switch (D54F) to ON. All meter lamps should light. The green lamps above the switches OSC. AMP. FIL. and AMPL. V.T. COOLING and RECT. FIL. should also light.

2. *Rectifier Filaments.* In order to allow proper preheating of the rectifier tubes the filaments should be energized before the rest of the equipment. Throw the switch RECT. FIL. (D7CD) to ON. The red light above this switch should light. Check the voltage of the three phases of the regulated supply by means of the POWER-SUPPLY VOLTMETER switch (D6F). Delay relays S2F and S16F are energized. After about twenty seconds relay S16F operates and after three minutes relay S2F operates followed immediately by relays S3F and S4F, lighting the RECTIFIER FILAMENT DELAY lamp (E10F). With all doors closed, and the high-voltage grounding switch open, all the door lamps will light and the bias contactor S4P will operate, energizing the bias rectifier and lighting the POWER AMP. BIAS lamp (E22F). The bias voltmeters (M2F and M3F) should indicate the proper bias voltages.

3. *Oscillator-Amplifier Filaments.* The oscillator-amplifier filaments may be energized at any time but preferably should be started a few minutes before the rectifier filaments have been completely preheated. Throw the OSC. AMP. FIL. switch (D6CD) to ON operating contactor S54F. Keep *all* switches in the oscillator-amplifier itself in the ON position.

4. *Cooling System.* Keep the safety disconnect switches D1W and D2W, or D8C, closed except when servicing the associated pump or blower motors. Set the valves of the water system (405A-2 R.T.E. only) as instructed in the section covering this system; then place the system in operation by closing the switch AMPL. V.T. COOLING (D8CD) to ON. Relay S5P operates, starting the cooling system motors.

When the proper water (or air) flow is obtained the flow relay WD1W (or AD1C) and relay S1F operate. Lamp E8F, COOLING SYSTEM lights and the green lamp above the switch AMP. FIL. lights, indicating that the filaments may be energized. In the 405A-2 equipment, the radiator fan motor may be started in cold weather by D2W after the amplifier filaments are energized, as described in the section covering the water system.

5. *Amplifier Filaments.* Close the switch AMP. FIL. (D9CD) thus energizing relay S2P and supplying power to the power amplifier filaments.

6. *High-Voltage Control.* At the same time that the bias rectifiers are energized the control circuit is complete to the high-voltage control of the oscillator-amplifier unit. With the switch PLATE RECTIFIER (D4A) in the ON position, the green lamp above the switch OSC. AMPL. PLATE (D10CD) lights. Throw this switch ON, operating S3A and energizing the plate rectifier of the oscillator-amplifier unit.

As soon as all amplifier filaments and bias rectifiers have been energized, the control circuit of the high-voltage rectifier for the power amplifier is completed and the green light above the switch H.V. RECT. (D11C) lights.

Close switch D11CD energizing the closing circuit for the plate circuit breaker. The lamp H.V. RECT. CIRCUIT BREAKER—OPEN (E26F lights. As soon as the breaker is closed the lamp is extinguished and the lamp CLOSED (E27F) lights. The rectifier is energized and the meter POWER AMP. PLATE (M7F) should read about 12 kv. The LAMP RESET (K3F) should be pushed to light the overload lamps. If any of these lamps become extinguished it indicates the operation of the protective or overload relay in the circuit designated below the lamp in question, and after noting the circuits the LAMP RESET button should again be operated to restore the indication circuit to normal.

7. *Operation at Reduced Power.* For full power (5 kw) operation switch POWER CHANGE (D12CD) should be in FULL position. By operating this switch to REDUCED, the carrier power is decreased to either 2.5 kw or 1 kw, depending on the connections to the primary of plate transformer T1P, as given in Table 8, with corresponding connections to the power amplifier biasing resistors R1K and R2K to give the bias voltages specified in Table 7.

With switch D12CD in REDUCED position, R56A should be adjusted to give the required antenna current for the reduced power (2.5 kw or 1 kw). This adjustment is made without changing the position of R4A from that required for full power.

When operating at 1 kw difficulty may be experienced in securing sufficient rectified current to operate relay S8A. This may be corrected by reducing potentiometer R55A to zero.

In order to operate at the same audio input level for both full and reduced power, an audio pad R78A to R82A inclusive should be installed. This pad is shunted out by the contacts of relay S9A for full-power operation. The proper resistors for this pad are supplied, and should be connected in circuit at the time of installation.

When changing from low to high power or vice versa, the OSC. AMPL. OVERLOAD RESET button D13CD should be held in, the power-change switch operated, and the overload reset button held in continuously until the transmitter is in operation at the new power. When the power change is made a transient surge through the feedback circuit may cause unwanted operation of the oscillator-amplifier overload relay S7A, and holding the overload reset button as above described is preferable to the introduction of a more complicated relay chain to avoid this condition. Since the overload relay in question is connected in the "trip-free" manner, this operation introduces no hazard to the equipment.

10-9i. Switch Functions

1. *Oscillator-Amplifier*

D1A—OSC. HEATER—Disconnect switch in power supply to the oscillator heaters. Leave in ON position.

D2A—POWER SUPPLY CCT BREAKER—Circuit breaker in power supply to oscillator-amplifier. Leave in ON position except when working in this unit.

D3A—POWER—Disconnects switch to turn oscillator-amplifier ON and OFF. Leave in ON position.

D4A—PLATE RECTIFIER—Controls high-voltage rectifier in oscillator-amplifier unit. Leave in ON position and control this rectifier from switch D5F designated OSCILLATOR AMPLIFIER PLATE VOLTAGE in control unit.

D5A—OSCILLATOR—This switch selects either of the oscillators provided in the unit.

D6A—Link switch in d-c plate supply of 3rd RF amplifier. Leave closed except when neutralizing this stage.

D7A—Link switch to remove plate voltage on 2nd audio stage. Mechanically coupled to D6A.

D9A—Gate switches.

D10A—TEST METER—Connects the test meter M2A to the various circuits in this unit.

D11A—OSC. AMPL. OVERLOAD RESET—A momentary contact push button for resetting the plate overload circuit.

D13A—Link switch for adding capacity to neutralizing condenser C15A. Leave closed.

D17A—Link switch—close to portion 3 to neutralize 3rd radio-frequency amplifier. Close to position 4 to tune RF by-pass circuit. Close to position 2 to adjust feedback and monitor rectifiers. Leave in position 2.

2. *Power Amplifier*

D1C—DOOR RELEASE—Momentary push button to operate electric door latches. Energizes the latches only if the rectifier grounding switch and door mechanism has been operated to ground the high voltage.

D2C to D5C—Door switches.

D7C—PROTECTIVE CIRCUIT switch. Close to disable protective circuit. Normally leave open except during initial adjustments.

K1C—FILAMENT VOLTAGE—Switches M3C to filament of either tube. Leave in either position.

3. *Control Unit*

D1F—RECTIFIER FILAMENTS—Operates contactor to energize bias and high voltage rectifier filaments. Energizes rectifier filament delay relays, the gate switch chain, and the bias rectifiers.

D2F—COOLING SYSTEM—Operates contactor to start cooling system motors and line starter to start pump.

D3F—AMPLIFIER FILAMENTS—Operates contactors to energize tube filaments of power amplifier. The operation of this switch is effective only if the water system is operating properly.

D4F—HIGH VOLTAGE RECTIFIER—Close to operate circuit breaker to energize the high-voltage rectifier. This control is dependent upon the cooling system, amplifier filaments and bias rectifiers.

D5F—OSCILLATOR-AMPLIFIER PLATE VOLTAGE—With D4A closed this switch is used to apply and remove plate voltage in the oscillator-amplifier unit.

D6F—POWER SUPPLY VOLTMETER—Connects M1F to any phase of the regulated power supply.

D9F—FULL POWER and REDUCED POWER—Transfers primary taps on high-voltage plate transformer (T1P) through relays S7.1P or S7.2P, and changes the power amplifier bias voltages through relays S1K and S2K.

D10F—OSCILLATOR-AMPLIFIER FILAMENTS—This operates a contactor to supply power to the oscillator-amplifier.

D11F—OSCILLATOR-AMPLIFIER CONTROL—In the test position this switch permits operation of the oscillator-amplifier unit alone. The bias rectifiers for the power amplifier are de-energized. In the operate position, the gate switches and plate control of the oscillator-amplifier are tied in to the control circuit of the rest of the transmitter. Leave in the OPERATE position.

D12F—PROTECTIVE CIRCUIT—This switch removes the control power from the protective circuit. Leave in ON position, except for tuning of power amplifier.

D53F—A-C CONTROL CIRCUIT POWER—This is a thermal type overload circuit breaker which controls the a-c control circuit power. Leave in the ON position.

D54F—D-C CONTROL CIRCUIT POWER—This is a thermal type overload circuit breaker which controls the a-c to a copper-oxide rectifier which in turn supplies the d-c control-circuit power. Leave in the ON position.

K1F—RECTIFIER FILAMENT DELAY RELEASE—A momentary contact push button to lock up S4F without waiting for operation of delay relays. May be operated in an emergency after a power interruption when the operator may prefer to risk a shortening of the life of rectifier tubes in order to avoid loss of program time.

K2F—CIRCUIT BREAKER RECLOSE—This momentary contact push button may be operated to reclose the plate circuit breaker CB10P after it has been tripped open twice in rapid succession and the recloser will not operate automatically.

K3F—LAMP RESET—A momentary contact push button which may be operated to reset the overload lamps after an overload indication.

K5F—OSCILLATOR-AMPLIFIER OVERLOAD RESET—This momentary contact push button may be operated to reset the oscillator-amplifier overload.

4. *Power Equipment.* All manual circuit breakers in the distribution cabinet should be kept in the ON position. In case any of these breakers trip open due to an overload they should be reclosed by first throwing to the OFF position to latch the handle and then throwing to ON.

5. *Cooling System.* Circuit breakers D1W and D2W (405A-2), or switch D8C (405B-2) should be kept in the ON position.

6. *Control Desk.* The control circuit switches in the desk operate in conjunction with control unit switches described above, as follows:

D6CD	operates 3 way with	D10F
D7CD	operates 3 way with	D1F
D8CD	operates 3 way with	D2F
D9CD	operates 3 way with	D3F
D10CD	operates 3 way with	D5F
D11CD	operates 3 way with	D4F
D12CD	operates 3 way with	D9F
D13CD	operates with	K5F
D14CD	operates with	K2F

10-9j. Lamp Functions—The control desk lamps are omitted from the following description. They operate in parallel with control unit lamps.

1. *Operation Lamps*[5]

E1F—Green lamp above D1F RECTIFIER FILAMENTS.

E3F—Green lamp above D2F—COOLING SYSTEM.

E54F—Green lamp above D10F—OSC.-AMP. FILAMENTS.

The above three lamps light as soon as power is supplied to the control circuit. They are extinguished only by opening the main disconnect circuit breaker CB1P, the branch circuit breaker CB3P, the a-c control-circuit breaker D53F, or a failure of T1F.

E2F—Red lamp above D1F RECT. FIL. lights when D1F is ON.

E4F—Red lamp above D2F COOLING SYSTEM lights when D2F is ON.

E55F—Red lamp above D10F OSC.-AMP. FIL. lights when D10F is ON.

E5F—RECTIFIER FILAMENTS White lamp on vertical nameplate. Lights when D1F, RECT. FIL. switch, is in ON position.

E6F—Green lamp above D3F AMP. FIL. lights when the COOLING SYSTEM is ON and the flow relay WD1W (or AD1C) has operated to energize S1F.

E7F—Red lamp above D3F AMPLIFIER FILAMENTS lights when D3F is thrown to ON provided the green lamp is also lighted.

E8F—White light on vertical nameplate COOLING SYSTEM lights under same conditions as E6F.

E9F—AMPLIFIER FILAMENTS lights when D3F is ON and has energized the filament contactor S2P.

E10F—RECTIFIER FIL. DELAY lights provided E5F has lighted and delay relays S2F and S16F have operated or K1F has been operated to energize S4F.

E11F—OSC. AMP. GATE lights after E10F lights provided D11F is in the OPERATE position and all doors on oscillator-amplifier unit are closed.

E12F—ANT. COUP. GATE lights after E11F provided door switches on the antenna coupling unit are closed.

E13F—POWER AMP. GATE lights after E12F provided all doors on the power amplifier unit are closed.

E15F—H. V. RECT. GATE lights provided the high-voltage grounding switch is open and the gate to the enclosure is closed and properly locked.

E19F—Green lamp above D5F OSC. AMP. PLATE VOLTAGE lights after E15F provided D4A PLATE RECTIFIER is left in ON position. Indicates D5F may be operated to apply plate voltage in the oscillator-amplifier unit.

E20F—Red lamp above D5F OSC. AMP. PLATE VOLTAGE indicates D5F is in ON position.

E21F—POWER AMP. BIAS lights after E15F provided contactor S4P operates to energize the power amplifier bias rectifier.

E23F—Green lamp above D4F H. V. RECTIFIER lights after E9F AMP. FIL. provided contactor S4P operates to energize the power amplifier bias rectifier. Indicates the transmitter is ready for the application of high voltage.

E24F—Red lamp above D4F H. V. RECTIFIER lights with E23F if D4F is thrown to ON.

E26F, E27F—HIGH VOLTAGE RECT. CIRCUIT BREAKER, OPEN — CLOSED indicates the position of the plate circuit breaker after D4F has been thrown to ON and E24F lights. If E24F is lighted, E27F indicates the breaker is in the OPEN position. The breaker may be closed by operating K2F CIRCUIT BREAKER RECLOSE. E26F will then light.

E53F—FILTER CONDENSER SWITCH lights when the plate-circuit breaker is closed and after the delay relay S13F has operated S1P, short-circuiting the condenser charging resistance.

This is the last OPERATE lamp to light and indicates that all power circuits have been properly energized.

2. *Overload Lamps*[6]

E30F—POWER AMP. V2 is extinguished by the operation of overload relay S2C.

E31F—POWER AMP. F1 is extinguished by the operation of overload relay S1C.

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[5] Associated with each lamp is a series resistor. The lamp will be extinguished by a failure of either the lamp or resistor.

[6] These lamps are energized from transformer T2F through contacts on the lamp relays, the coils of which receive current from the copper-oxide rectifier X1F supplied from transformer T4F. They are lighted only by the operation of key K3F designated LAMP RESET. Once lighted they are extinguished individually by the operation of some overload or protective relay. The opening of the A-C CONTROL CIRCUIT POWER or D-C CONTROL CIRCUIT POWER switches (D53F or D54F) will extinguish all of them.

E48F—HIGH VOLTAGE RECTIFIER D-C is extinguished by the operation of overload relay S1G.

E50F—HIGH VOLTAGE RECTIFIER CCT. BKR. is extinguished by any circuit operation that opens the plate-circuit breaker. If this lamp (E50F) is extinguished without any other lamp indicating a circuit abnormality, then the a-c trip elements in the breaker have operated to open the breaker or the control circuit for the breaker has opened.

E51F—PROTECTIVE CIRCUIT is extinguished by the operation of relay S3C which energizes relay S10A to momentarily remove the carrier.

E52F—OSC. AMP. is extinguished by the operation of S7A which occurs when the 3rd amplifier stage of the oscillator-amplifier draws abnormal plate current.

10–9k. Supplementary Notes

1. *Fuses.* The only fuses used in the equipment are as listed in Table 11. Each fuse should be tested for continuity before placing in the fuse mounting.

2. *Indicating Lamps.* Western Electric type K1 lamps are used for indicating lamps in the control unit and oscillator amplifier unit. General Electric Mazda No. 46 lamps are used to illuminate the meters.

3. *Vacuum Tubes.* The types of vacuum tubes used and their circuit designations are given in Table 12.

4. *Rectifier Tubes.* The life of the 315A vacuum tube is greatly affected by the care that is taken to make certain that these tubes have been thoroughly warmed before the application of plate voltage. The relay S2F which is incorporated in the control circuit of this equipment prevents the application of plate voltage for three minutes, but it is advantageous when time permits to use a longer preheating time particularly when the ambient temperature is low. Tubes which have not been operated for 48 hours should be run with filament voltage for 30 minutes before applying plate voltage. New tubes should be operated with filament voltage for at least two hours before application of plate voltage. If at the end of this time it appears that any mercury is still condensed on the anode or upper part of the tube, particularly on the glass near the anode seal, the heating should be continued until all of this mercury has been evaporated and deposited in the lower end of the tube. If this preheating is done at reduced filament voltage, as is done when the tube is inserted in the spare tube socket, the preheating time should be increased to four hours. If a new tube arcs back on application of plate voltage the filament should be heated further and the tube tried several times again before the tube is rejected.

When first received all 315A vacuum tubes should be tested, after first warming the tube filaments as described above, by operating the tubes in the rectifier at reduced plate voltage (power-change switch in REDUCED POWER position) for five minutes. The tubes should then be operated at full voltage for approximately ten minutes. Tubes kept as spares should be given a similar test monthly to make certain that slow leaks or other troubles may not have developed while in storage.

5. *Air Filter.* The spun-glass air filter in Unit C of the 405B-2 equipment may be cleaned, when and if necessary, by removing it from the unit, and pouring water through it, from the inside to the outside. Also, the outside may be brushed to remove any accumulated dust. Warm water or carbon tetrachloride may be used if there is any indication of a grease deposit on the filter.

6. *Motor Blower Lubrication.* The blower oil cups should be occasionally filled with a medium machine oil. The motor has grease-packed ball bearings and requires infrequent attention, instructions for which are printed on a card attached to each motor. The motor and blower are accessible through the front doors.

TABLE 1

D-151215 OSCILLATOR-AMPLIFIER
TYPICAL METER READINGS

Design No.	Title	Reading
M3A	Plate Rectifier	2950 to 3050 volts
M4A	3rd Amp. Plate Current	150 to 200 ma.
*M5A	3rd Amp. Plate Current	0.4 to 0.8 ampere
M7A	Antenna Current	$I_A = \sqrt{P/R_a}$
M2A	"Test Meter" Switch Position:	
	Osc. No. 1 Grid/2	.05 to .1 ma.
	Osc. No. 2 Grid/2	.05 to .1 ma.
	Osc. Plate x 10	2 to 5 ma.
	V1 Plate x 20	2 to 12 ma.
	V2 Grid x 5	0 to 4 ma.
	V2 Plate x 100	40 to 60 ma.
	3rd Amp. Grid x 10	0–1 ma.
	V3 Plate x 200	80 to 110 ma.
	V4 Plate x 200	80 to 110 ma.
	V5 Plate x 200	Not used
	V6 Plate x 10	5 to 9 ma.
	V7 Plate x 100	30 to 35 ma.
	V8 Plate x 100	30 to 35 ma.
	V9 Plate x 20	6 to 10 ma.
	V10 Plate x 20	6 to 14 ma.
	Bias Load x 200	120 to 160 ma.

*M5A will not indicate after L10A is disconnected.

TABLE 2

D-151215 OSCILLATOR-AMPLIFIER
PLATE SCREEN AND FILAMENT VOLTAGES

Desig. No.	Plate	Screen	Grid	Filament
V1A, V2A, V7A & V8A	450 to 500	180 to 200	325	12.4 to 12.8
V3A, V4A	2950 to 3050		325	13.7 to 14.3
V6A	200 to 250	170 to 190		9.8 to 10.2
V9A & V10A				6.1 to 6.5
V11A				4.9 to 5.1
V12A to V15A incl.				2.45 to 2.55
V16A				1.3 to 1.7
V1A of 702A Osc. No. 1 & No. 2	240 to 260 at Term. 2			1.95 to 2.05

TABLE 3

D-151215 OSCILLATOR-AMPLIFIER PRELIMINARY COIL ADJUSTMENTS

Freq.	L3A		L5A		L10A	
	Active Turns	Unused Turns	Active Turns	Unused Turns	Active Turns	Unused Turns
550	56	Open	55	Open	42	Open
600	50	Open	50	Open	40	Open
700	46	Open	43	Open	35	Open
800	42	Open	37	Open	32	Open
900	39	Open	32	Open	29	Open
1000	36	Open	28	Open	27	Open
1100	34	Open	24	Open	25	Open
1200	31	Open	21	Shorted	24	Open
1300	29	Open	18	Shorted	22	Open
1400	28	Open	15	Shorted	21	Open
1500	27	Open	13	Shorted	20	Open
1600	25	Open	11	Shorted	18	Open

L1A

550 — 1000 kc Use entire coil.
1010 — 1600 kc Short upper section.

L8A

550 — 800 kc Use entire coil.
810 — 1200 kc Use 2 sections.
1210 — 1600 kc Use 1 section.

CONDENSER ADJUSTMENTS

It will be necessary to add fixed condensers C51.1A to C51.3A to variable condenser C20A depending upon the grid input adjustment of the Power Amplifier unit.

TABLE 4

D-151215 OSCILLATOR-AMPLIFIER RESISTANCE ADJUSTMENTS

Resistance Designation	Terminations On Designated Resistance	Approx. Resistance in Ohms
R61A	First slider to lower end	600
R61A	First slider to second slider	400
R60A	Second slider on R61A to first slider on R60A	5000
R60A	First slider to second slider	4200
R62A	First slider to lower end	5000
R62A	First slider to second slider	5000
R63A	Second slider on R62A to slider on R63A	5600

VOLTAGES WITH ABOVE ADJUSTMENTS

Designation	Termination On Designated Resistances	Approximate Voltage
R61A	First slider to lower end (ground)	14 to 20
R61A	Second slider to ground	30 to 50
R60A	First slider to ground	190 to 210
R60A	Second slider to ground	460 to 510
R60A	First slider to ground	80 to 100
R62A	Second slider to ground	240 to 250
R63A	Slider to ground	430 to 450
R65A	Third slider to ground	325 to 375
R65A	Second slider to ground	325 to 375
*R45A	Slider to ground	450 to 500

* Adjustment of the slider on R45A may require a readjustment of the slider on R63A to bring the screen voltage of V7A and V8A within the limits specified in Table 2.

TABLE 5

D-151239 (OR D-151218) POWER AMPLIFIER PRELIMINARY ADJUSTMENTS

Carrier Freq. kc	L3C	L5C	L6C	L7C Sect	L8C Sect	L9C	L10C	L11C	L12C Sect	L13C	L14C	L15C	L16C Sect	L17C Sect	L18C	C10.1 C	C10.2 C	C20C	C21C	C22C
550	110	115	110	9	10	120	37	15	5	85	125	80	8	8	17	.0025	.02	.0004	.0025	.0025
600	100	95	92	9	10	100	35	16	5	75	120	72	8	8	12	.0025	.02	.0004	.0025	.0025
700	90	82	80	8	10	115	32	20	5	68	100	66	7	7	20	.002	.02	.00035	.0015	.0015
800	90	65	62	8	10	70	28	20	4	62	90	60	7	7	17	.0015	.015	.00025	.0015	.0015
900	75	55	53	8	10	54	30	20	4	61	80	55	6	6	15	.0015	.015	.0002	.0015	.0015
1000	65	52	49	8	9	45	29	15	4	56	80	50	6	6	18	.0015	.015	.0002	.001	.001
1100	58	43	40	7	9	42	28	12	4	50	70	47	5	5	17	.0008	.008	.00015	.001	.001
1200	70	48	45	7	9	35	27	16	3	46	60	43	5	5	17	.0008	.008	.00015	.0008	.0008
1300	58	42	40	6	9	26	26	16	3	42	50	39	4	4	15	.0005	.005	.0001	.0008	.0008
1400	53	40	36	5	9	31	25	17	3	29	40	36	4	4	13	.0005	.005	.0001	.0008	.0008
1500	46	37	34	5	8	29	18	18	2	25	30	26	4	4	13	.0005	.005	.0001	.0008	.0008
1600	40	34	30	4	7	26	12	19	2	20	20	20	3	3	12	.0004	.004	.00005	.0006	.0006

All above coil settings are approximate only, and are given merely for convenience in arriving at the correct adjustment as described in the text with a minimum of difficulty.

TABLE 6

D-151239 (OR D-151218) POWER AMPLIFIER
TYPICAL METER READINGS

Desig. No.	Title	5 kw	Reading 2.5 kw	1 kw
M1C	Plate Current V1	.58–.60 A	.38–.56 A	.24–.3 A
M2C	Plate Current V2	.09–.11 A	.05–.08 A	.02–.04 A
M3C	Filament Voltage	20–21.5 V	20–21.5 V	20–21.5 V
M4C	Grid Load Current	70–110 MA	60–90 MA	60–90 MA
M5C	Total Plate Current	.68–.70 A	.46–.51 A	.26–.315 A
M6C	Trans. Line Current or Antenna Current			
M7C	d c Protective Circuit	0–3 MA	0–2 MA	0–1 MA

TABLE 7

D-151238 (OR D-151219) CONTROL UNIT
TYPICAL METER READINGS

Desig. No.	Title	5 kw	Reading 2.5 kw	1 kw
M1F	Power Supply	230 V	230 V	230 V
M2F	P. A. Bias V1	300 V	300 V	275 V
M3F	P. A. Bias V2	450 V	350 V	350 V
M7F	P. A. Plate	11.8–12.2 KV	8.2–8.4 KV	5.3–5.4 KV
M8F*	Leakage Current (Max.)	2 MA	2 MA	2 MA
M10F*	Water Pressure	10–25 lbs.	10–25 lbs.	10–25 lbs.
TD1F*	Water Temperature	75°–180° F.	75°–150° F	75°–150° F.

* *Note:* M8F, M10F, and TD1F are omitted in the 405B-2 Equipment.

TABLE 8

H. V. PLATE TRANSFORMER CONNECTIONS
FOR REDUCED POWER

High Power	Reduced Power	Distribution Cabinet Terminals 41, 42, 43 Connected to	Distribution Cabinet Terminals 34, 35, 36 Connected to
5 KW	2.5 KW	X8, X9, X7	X4, X6, X5
5 KW	1.0 KW	X11, X12, X10	X4, X6, X5
2.5 KW	1.0 KW	X11, X12, X10	X7, X9, X8

TABLE 9

OVERLOAD RELAY ADJUSTMENTS

Designation No.	Set to Operate at	Adjust. by Means of
S7A	0.7 amp.	R67A
S1C	1.0 amp.	Relay adjusting screws
S2C	1.0 amp.	Relay adjusting screws
S1G	2.0 amp.	R2G

TABLE 10

SAFETY GAP SETTINGS

Gap	Spacing
G1C	.010 inch
G2C	.010 inch
G1G	.010 inch
Gap on Plate Retard (L1P)	0.30 inches

TABLE 11

FUSES

Desig. No.	Current Rating	Cat. No.
F1.1A	5 Amp 250 Volts	D&W Cat. No. 1456
F1.2A	5 Amp 250 Volts	D&W Cat. No. 1456
F2.1A	2 Amp 250 Volts	D&W Cat. No. 91002
F2.2A	2 Amp 250 Volts	D&W Cat. No. 91002
F3A	1 Amp 2500 Volts	D&W Cat. No. 2760

TABLE 12

VACUUM TUBES

Unit	Designation	Code No.	Desig- nation	Code No.
D-151215 Oscillator Modulator	V1A	RCA 837	V10A	345A
	V2A	RCA 837	V11A	274A
	V3A	241B	V12A	249B
	V4A	241B	V13A	249B
	V6A	310A	V14A	249B
	V7A	RCA 837	V15A	249B
	V8A	RCA 837	V16A	249B
	V9A	345A	V1 of 702A Osc. No. 1	247A
			V1 of 702A Osc. No. 2	247A
D-151239 (or D-151218) Power Amplifier	V1C	343A 405A-2 343AA 405B-2		
	V2C	343A 405A 2 343AA 405B 2		
	V3C	274A		
D-99114 (or D-151224) High Voltage Rectifier	V1G	315A		
	V2G	315A		
	V3G	315A		
	V4G	315A		
	V5G	315A		
	V6G	315A		
	V7G (Spare)	315A		
	V1K	249B		
	V2K	249B		
	V3K	249B		
	V4K	249B		
D-151238 (or D-151219) Control Unit	V1 of S16F	313A		

10–10. RCA Type 1–K Broadcast Transmitter—The RCA type 1–K broadcast transmitter equipment is identified by the stock number MI–7186–A and is comprised of the following items:

1 type 250–K exciter
1 type 1–K power-amplifier unit
1 type 1–K power equipment section
2 type TMV–129B crystal unit, complete with crystal
1 power-change equipment (supplied only if 250/500, 250/1000 or 500/1000 watt operation is desired)
2 sets tubes
1 set miscellaneous hardware
1 r-f output meter

The RCA type 1–K amplifier equipment, for use with a 250–K transmitter already installed, is identified by the stock number MI–7187, which is comprised of the following items.

1 type 1–K power-amplifier unit
1 type 1–K power equipment section

1 conversion kit (to convert type 250-K transmitter for use as an exciter)
1 power-change equipment (supplied only if 250/500, 250/1000 or 500/1000 watt operation is desired)
2 sets tubes for 1-K power amplifier-modulator and 1-K power equipment section
1 r-f output meter

10-10a. Technical Summary

1. *Electrical Characteristics*

Frequency Range: 550 to 1600 kc
Frequency Stability: ±10 cycles
Carrier Shift: Less than 5% from 0 to 100% modulation (50 to 7500 cycles)
R-f Harmonics: Less than 0.05%
Power Outputs: 250/500, 250/1000, 500/1000, 500, 1000 watts
Output Circuits: Usual antenna, or 70 to 600 ohm transmission line
Type of Modulation: High level, Class B
Audio Input Level—
  At 100% modulation (sine wave): +11 vu
  At average program level: +5 vu
Audio Response: Within ±1.5 db from 30 to 10,000 cycles
Audio Distortion: Less than 3% r-m-s—from 50 to 7500 cycles
Noise Level: 60 db below 100% modulation level
Main Power Supply: 220 to 240 volts, 50/60 cycles, single phase
  Permissible Line Voltage Variation: ±5%
  Power Consumption at 1000 watts r-f output:
    (at 100% modulation) approx. 5700 watts
    (at average program level) approx. 4500 watts
  Power Consumption at 500 watts r-f output:
    (at 100% modulation) approx. 4900 watts
    (at average program level) approx. 3700 watts
  Power Consumption at 250 watts r-f output:
    (at 100% modulation) approx. 4450 watts
    (at average program level) approx. 3350 watts
  Crystal Heater Power Supply: 115 volts, 50/60 cycles, single phase
  Power Consumption: 30 watts

2. *Tube Complement*

Exciter—Amplifier Unit "250-K"—
  Crystal Oscillator: 1 RCA-802
  Buffer: 1 RCA-828
  Intermediate Power-Amplifier: 1 RCA-810
  First Audio: 2 RCA-6J7
  Second Audio: 2 RCA-828
  Main Rectifier: 2 RCA-872
  Bias Rectifier: 1 RCA-80
Power-Amplifier Unit—
  Power-Amplifier: 2 RCA-833-A
  Modulator: 2 RCA-833-A
  Bias Rectifier: 2 RCA-866
  Main Rectifier: 4 RCA-872

3. *Mechanical Specifications*

  Number of Cabinets: 3
  Type of Construction: Vertical Chassis
  Floor Area: 14.5 sq. ft.
Dimensions (overall)—
  Width: 108¾ inches
  Height (including lead-in bushings): 84⅞ inches
  Depth: 20⅛ inches
  Depth (including rear door swing): 38⅞ inches
Weight (net)—
  Exciter-Amplifier Unit: 1360 pounds
  Power Amplifier-Modulator Unit: 1000 pounds
  Power Equipment Unit: 1050 pounds
  Total Floor Load: 3410 pounds

10-10b. Description—This transmitter will provide reliable, high-fidelity operation at any frequency between 550 and 1600 kc with negligible distortion and low carrier noise. It is very easily installed, requiring only the connection of external wiring and the bolting of cabinets together. When the type 1-K amplifier equipment is being added to an existing 250-K installation, several minor alterations are required to convert the 250-K transmitter into an exciter for the type 1-K transmitter. A conversion kit is supplied with the equipment to facilitate the changeover. These changes have been made at the factory on the complete type 1-K transmitter. The equipment requires a single-phase power supply of 230 volts, 50/60 cycles. The transmitter will deliver rated power into a 70- to 600-ohm transmission line or into any type of antenna normally used with broadcast transmitters. Convenient terminals are provided for supplying energy to operate modulation and frequency monitors, and a monitoring amplifier.

The transmitter as normally supplied is wired for operation only at its full-rated power output of 1000 watts or only at a lower output of 500 watts. If it is desired to operate the equipment at 250/500, 250/1000 or 500/1000 watts, this may be accomplished by using the power change equipment kit listed under EQUIPMENT. This kit may be added to the transmitter at any time.

10-10c. Construction—The cabinet enclosures are designed to produce a unified and distinctive appearance as shown by Figure 10-20. All necessary controls are grouped conveniently on illuminated panels. Adjustments are facilitated by the liberal provision of meters, which are mounted at eye level on hinged panels located just above the controls.

Access to the rear of each meter panel is obtained by first operating the release handle, which is reached through a chassis hand-hole from the rear, and then by swinging the panel forward. The panel is held in its raised position by stay joints. The handle which operates the panel-catches operates, in addition, a high voltage interlock switch.

All transmitter components are mounted on vertical type chassis and each is readily accessible from the rear through full-length doors. The opening of these doors operates high-voltage interlock switches. In making repairs and replacements it is necessary to remove the chassis. The edges of all wire holes are rounded, and the holes are of sufficient size to permit wires to be removed or replaced easily should this ever be necessary. Sufficient lengths of wire are provided to permit easy removal of the terminal boards and high voltage terminals. Shields are placed behind the high-voltage terminal bushings to protect them against accidental short circuits. The bushings may be removed and the wires "fished in" if necessary.

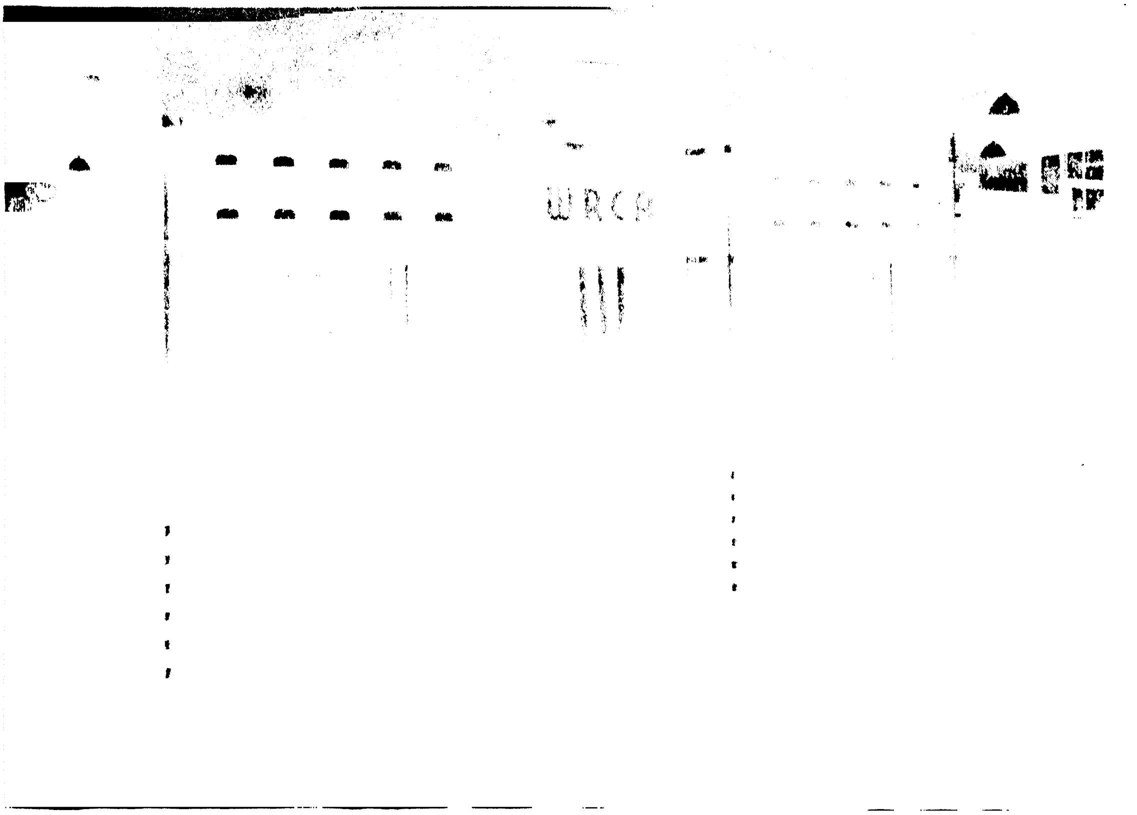

FIG. 10–20. RCA 1-k standard broadcast transmitter.

The equipment is mounted in three cabinets, shown in Figure 10–22 as the 250–K EXCITER, the center unit, and the 1–K AMPLIFIER. The 250–K EXCITER includes the crystal oscillator, the low-power audio and radio-frequency stages, and their power supplies. The center unit contains the heavy power and modulation transformers. The 1–K amplifier cabinet contains the power-amplifier stage, components of the modulator stage, and their power supplies.

10–10d. Circuit Design—A schematic diagram for the complete transmitter is given in Figure 10–22. It will be noticed that the circuit is divided into two sections, one labeled TYPE 250–K EXCITER and the other TYPE 1–K AMPLIFIER. The various items of the first section are designated by code numbers prefixed by the number "1"; the items of the second section have code numbers prefixed by the number "2." The various sub-divisions of the "250–K" section will be referred to in the following discussion as: oscillator; buffer; intermediate power-amplifier; first audio stage; second audio stage; second audio bias rectifier; exciter plate-voltage rectifier. The sub-divisions of the "1–K" section consist of the power-amplifier, modulator, modulator bias rectifier and power-amplifier plate-voltage rectifier.

The names of the switches and controls on the 250–K panel are, in some cases, the same as those on the 1–K panel. To avoid confusion, references to controls located on the 250–K panel will include the control name, preceded by the word "exciter" or by "250–K." Similarly, names of the 1–K panel controls will be preceded by the word "amplifier" or by "1–K."

1. *Radio-frequency Circuits.* Excellent frequency stability is attained by the use of a low temperature-coefficient crystal installed in a temperature-controlled chamber, and connected between the control and screen grids of the RCA–802 oscillator tube. Vernier frequency control is obtained by an adjustment of capacitor 1C2 which is connected in parallel with the crystal.

Two stages of r-f amplification follow the oscillator stage. The first, or buffer, stage uses an RCA–828 tube and the second, the intermediate power-amplifier, uses an RCA–810 tube. The power-amplifier stage includes two RCA–833–A tubes, connected in a push-pull circuit.

The power-amplifier is inductively coupled to the antenna or transmission line through a "T" section

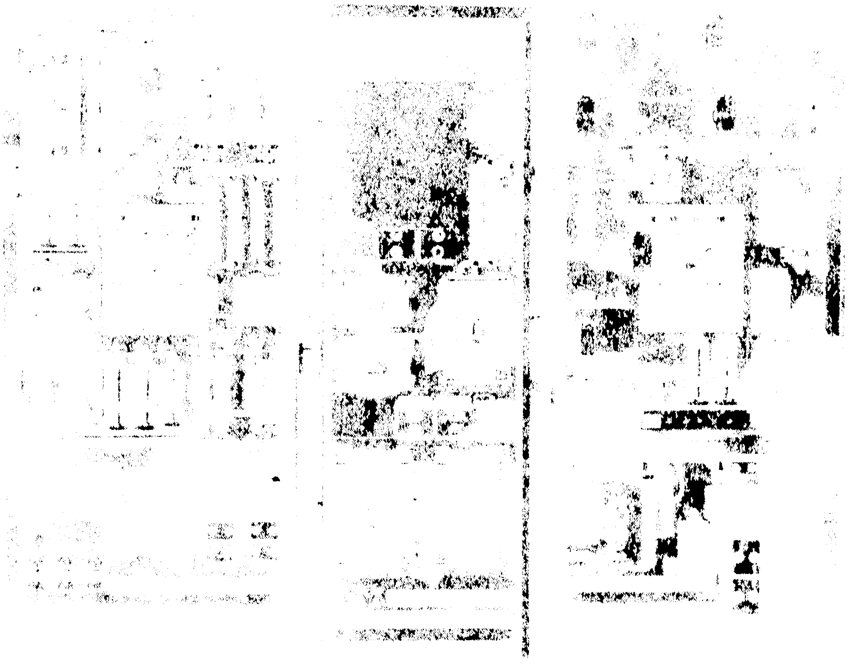

FIG. 10–21. Rear view of RCA 1-K broadcast transmitter.

filter, which effectively reduces radio-frequency harmonics.

2. *Audio-Frequency Circuits.* The audio-frequency amplifier consists of two stages of push-pull amplification, the first containing two RCA–6J7 tubes and the second two RCA–828 tubes operated Class A. The modulator contains two RCA–833–A tubes.

The use of negative feedback around the three a-f stages results in an extremely low order of distortion. The entire audio system is designed in such a manner that it is inherently stable.

A 6-db pad (1A8), is connected across the primary side of the input transformer to the first stage of audio amplification. If it becomes desirable, for any reason (such as insufficient audio level at the output of the line amplifiers), this pad may be eliminated from the circuit without any serious consequent change in the performance of the transmitter.

3. *Control Circuits.* The control circuits serve to provide convenient operation and adequate protection to the tubes and other components. No fuses are used except in the crystal heater circuit, protection elsewhere being afforded by magnetic or thermal circuit breakers.

When the main LINE breaker (2S1) is open, all power is removed from the transmitter. However, voltage is still present in the connections between the power input terminals and this breaker, and power is still applied to the crystal heating circuit. When this breaker is closed, the panel illuminating lamps (2A1 and 1A7) are lighted. The FILAMENT lamp of the 1–K panel is also lighted when the LINE switch (2S1) is closed. The FILAMENT breakers (1S2 and 2S2) protect all filament circuits and in addition, serve as filament switches. When these breakers are closed, and 2S1 and 1S1 are closed, filament power is available to all tubes. Under this condition, a buzz in the transmitter should be heard.

This buzz originates at the holding coils of the PLATE breakers (1S3, 2S3), and is an indication that the electrodes of the time delay relay (1E4) have not yet "closed." The PLATE breakers cannot be closed until this time delay relay which protects the rectifier tubes filaments has operated.

The time delay relay (1E4) is a plunger type, mercury-filled unit. A glass tube, containing two electrodes, is partially filled with mercury, on which floats an iron plunger. The tube is encircled by a solenoid, which is so positioned that when energized, it pulls the iron plunger down. The mercury displaced by the plunger rises and contacts the electrodes, thus closing that circuit. The velocity of rise of the mercury, or "delay," is controlled by the rate of gas seepage through the porous wall of a gas chamber. For this relay the design is such that an interval of about 30 seconds elapses before the electrode circuit is closed. The circuit is opened, however, about 2 seconds after the relay coil is de-energized.

When the time delay relay contacts are closed, the coil of the auxiliary relay (1E5) is energized. This latter relay de-energizes the holding coils of the PLATE breakers (1S3, 2S3), permitting these breakers to be closed (by operation of the front panel levers), and thus allowing application of the plate voltages. The 2 second opening time of relay (1E4) serves to prevent breakers (1S3, 2S3) from opening in case of a momentary power failure. In order to accomplish this, relay (1E5) operates considerably faster than breakers (1S3, 2S3).

Seven interlock switches (1S4, 1S8, 1S9, 2S5, 2S6, 2S7, 2S8) are connected in series with the primary power circuits of the plate transformers. The PLATE indicator lamps (1A4 and 2A2), located on the control panels, are connected directly across the primary terminals of the plate transformers. These lamps are illuminated when the transformers are energized.

4. *Power Supply Circuits.* A full-wave rectifier containing two RCA–872 tubes supplies plate voltage for the oscillator, buffer, and intermediate power-amplifier, and for the first and second stages of audio amplification. Bias voltage for the second audio stage is supplied by a rectifier using an RCA–80 tube. A full-wave, bridge type rectifier employing four RCA–872 tubes supplies plate power for the power-amplifier and modulator. Modulator bias is provided by a rectifier using two RCA–866 tubes.

Power reduction may be obtained by means of the resistors which are connected, in series with the high-voltage plate supply of the power-amplifier and by changing the connections to the taps on the plate transformer (2T7). The wiring diagram shows the connections which are required for different power operating conditions. For 500/1000-watt operation, the resistors 2R26 to 2R33 are combined to total 2050 ohms (maximum). For 250/1000-watt operation, these resistors are combined to total 4600 ohms (maximum). For 250/500-watt operation, the plate voltage is reduced by means of the taps on the plate transformer, and the change is obtained with the resistors combined to total 2050 ohms. One of these power change resistors is variable in order that adjustments may be made as required for a specific installation. When the power change is desired, these resistors may be inserted and removed from the circuit by means of a relay (2E1), which is operated by the POWER CHANGE switch, located on the control panel of the exciter unit. When the transmitter is to be operated only at 500 watts, the plate voltage may be reduced by means of the taps on the plate transformer. In this case the relay, resistors and switch are not employed. When the modulator is operated at reduced plate voltage, such as in 500 and 250/500-watt operation, it will be necessary to change wires numbered 43 and 44 from taps 1 and 2 on the modulator bias transformer (2T5) to taps 4 and 5.

5. *Monitoring Provisions.* Terminals 15C and 16C are provided for connection of an audio-frequency monitor. A maximum level of approximately + 10 vu is available. A jack is provided in the buffer stage for connection of the frequency monitor. Another jack is provided in the power-amplifier for connecting the modulation monitor. An extra plug is supplied to permit connection of a cathode ray oscillograph for sampling the r-f voltages.

10–10e. Preliminary Adjustments—All breakers should be opened before power is applied to the transmitter. It should be noticed that when the exciter P. A. OVERLOAD and MOD. OVERLOAD breakers, and the 1-K MOD. OVERLOAD breaker (1S5, 1S6 and 2S9 respectively) are open and high voltage is applied to the transmitter, the cathodes of the associated tubes are at a high potential with respect to ground.

Refer to the CAPACITOR AND P. A. TANK TAPS CHART and connect the proper capacitors [7] and taps in the various tank circuits. These circuits are normally adjusted for 1000 kc when shipped. Since some capacitors will have been relocated in 250-K exciters which have been converted from 250-K transmitters, it would be well to refer to the stock numbers and capacity values given in the parts list if any difficulty is experienced. A sufficient number of links and connectors are provided to enable the connecting of any capacitor combination required.

Check the primary tap connections on all transformers. Those in the exciter should be made to the 110 volt tap, with the exception of the plate transformer (1T5), which should be set on the 115 volt tap, so that the rated plate dissipation of the tubes will not be exceeded. The primary connections in the amplifier should be made to the 230 volt tap.

Insert all tubes in their proper sockets.

Caution. Do not connect the plate caps of the 6 RCA–872 rectifier tubes. Be sure that the plate caps of the RCA–828 tubes *are* connected.

Close the exciter and amplifier LINE breakers. The panel illuminating lamps (1A7, 2A1) should light and the LINE VOLTAGE meters (1M12, 2M11) should indicate. Adjust the variable transformer (2T2) until the meter 2M11 indicates 230 volts. Check all filament voltages. Adjust the controls 1R23, 1R27 and 1R28 (located on the back of the rectifier chassis) if variation of filament voltages in the exciter unit is necessary. All filament volt-

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[7] As stated previously, the terms "capacitor" and "condenser" can be used interchangeably.

ages should be brought to within 2 per cent of their rated value.

A total of about 95 volts should be available across the exciter bias-rectifier output. This voltage may be measured across 1C61. Set the potentiometers (1R22 and 1R54), which are located on the back of the 250-K rectifier shelf, fully clockwise to provide maximum 2nd audio amplifier bias voltage.

Allow the filament voltages to remain on. Insert the crystal holders in their proper sockets. Make certain that fuses (F1, F2) are installed in the fuse holders and then connect terminals 17B and 18B to a 115 volt power supply line. The crystal holders should reach their operating temperature (approximately 60° C, 104° F) in about 30 minutes. Do not proceed further with any adjustments requiring the application of plate voltage during this period, since the rectifier tubes should have filament voltage applied for approximately this length of time before the plate voltage is applied.

Note: When an RCA-872 tube is first placed in service, it should be operated for at least 15 minutes with the normal filament voltage, but without plate voltage applied, in order to properly distribute the mercury within the tube. This procedure need not be repeated unless during subsequent handling, the mercury is spattered on the filament or plate.

Caution. During all tuning adjustments, it is essential that the 250-K MODULATOR OVERLOAD and 1-K MODULATOR OVERLOAD breakers (1S6 and 2S9) be kept open. Since the audio system will oscillate violently if the feed-back connections happen to be reversed, the plate voltage must not be applied to the audio tubes until after the feed-back polarity has been checked. The check will be described later in this instruction book.

10-10f. Tabulation of Controls—

EXCITER (250-K)		AMPLIFIER (1-K)	
Panel Designation	Symbol No.	Panel Designation	Symbol No.
Buffer	1L5	P.A. Plate	2L6
P.A. Neut.	1L7	Modulator Bias, Left	2R16
P.A. Plate	1L9	Modulator Bias, Right	2R17
Power Output	1R15	Line Voltage	2T2
Loading	1L10	Power Output	2L7
*None	1L11		
Power Change	1S7	Mod. Overload	2S9
Mod. Overload	1S6	Line	2S1
Line	1S1	Filament	2S2
Filament	1S2	Plate	2S3
Plate	1S3	P.A. Overload	2S4
P.A. Overload	1S5		

* 1L11 is controlled by means of the knob at the rear of this inductor. It is accessible from the rear of the chassis after the rear doors have been opened. This control is referred to as "p-a grid tank coil."

10-10g. Tuning—The crystal oscillator utilizes an RCA-802 tube with the crystal connected between the control and screen grid. Any one of four reactors may be selectively connected in the plate circuit of this stage, each covering a portion of the total frequency range (550 to 1600 kc) as indicated in the tabulation which follows:

Band Coverage (kc)	*Coil*
550 to 700	4
700 to 1150	3
1150 to 1400	2
1400 to 1600	1

The tuned circuit comprising coil of 1L3 and capacitor 1C10 is provided so that this oscillator may be used to cover the frequency band of from 1600 to 2500 kc.

The proper coil in the oscillator plate circuit should be connected before plate voltage is applied. If the oscillator should be sluggish in starting, the coil listed for the next higher frequency band should be employed.

After the 30 minute "aging" interval has elapsed, connect the plate connectors to the 2 RCA-872 mercury-vapor rectifier tubes in the exciter unit. The exciter PLATE breaker (1S3) may then be closed, thus applying plate voltage to the high-voltage rectifier. The control circuits should then be checked to see that all elements operate properly as previously described. The PLATE breaker should be checked to determine that the holding coil functions properly during the thirty-second warm-up periods, and the operation of the auxiliary relay (1E5), should be checked thoroughly. Each of the rear doors should be opened separately while plate voltage is applied to the rectifier. Opening either door should remove the plate voltage. The meter panels should then be opened to check the operation of the meter panel interlock switches. It should not be possible to apply plate voltage to the rectifier while either meter panel is open.

This check should be repeated immediately after plate voltage has been applied to the 1-K rectifier.

When plate voltage is applied, three milliammeters should indicate current. They are, the OSCILLATOR PLATE (1M1); the 1ST AUDIO PLATE (1M9); and the BUFFER PLATE (1M2) meters. The indications on these meters should correspond to those given in the chart of TYPICAL METER READINGS.

The 1ST AUDIO PLATE meter should at first indicate approximately 2.5 ma. When plate voltage is later applied to the modulator stage, the plate current of this stage will change to that listed in the chart of TYPICAL METER READINGS. Measurement of plate current and plate voltages on the first a-f stage serves as a good check on these circuit elements. The plate voltages to this stage should be read with a high resistance voltmeter, i.e., one having a resistance of at least 1000 ohms per volt.

The oscillator may be checked for oscillation by removing the crystal holder from its socket. When this is done, the oscillator plate current should increase.

The buffer stage may be tuned by means of the control marked BUFFER (1L5). It should be adjusted to the point which produces maximum grid current (on meter 1M4) in the intermediate power-amplifier tube. Minimum plate current in the buffer tube should be obtained at approximately the same point. When adjustments are made in the intermediate power-amplifier stage, it may be necessary to readjust the BUFFER tuning. It will be noted that the tank capacitors are arranged to form a capacitance voltage-divider in such a manner that when the values designated are used, proper excitation is supplied to the intermediate power-amplifier grid. Links are provided for capacitor connections in all exciter circuits in order that connections may be readily changed.

Excitation for a frequency monitor is obtained from the potentiometer (1R14), which is connected across a capacitor in the ground side of the buffer-tank circuit. This potentiometer is provided in order that the excitation may be adjusted as required. After the frequency monitor has been adjusted, the frequency of the oscillator should be adjusted to zero beat with the monitor by means of the vernier capacitor (1C2), which is connected across the crystal. A screwdriver slot in a bakelite shaft, accessible from the rear of the oscillator unit, is provided for this adjustment. The spare crystal should also be checked against the frequency monitor by inserting it in the socket provided in the oscillator unit. The setting of capacitor 1C2 will probably be different for each of the two crystals.

A shunt is connected across the intermediate power-amplifier plate-tank meter thermocouple (1M8). This shunt should be removed during the neutralizing adjustment and then replaced. The shunt gives the meter a multiplying factor of approximately 1.6. After the transmitter has been completely adjusted and is operating at normal load, the shunt may be removed if the product of the meter indication and this factor (1.6) is less than 3 amperes.

The intermediate power-amplifier should first be neutralized. Disconnect the two leads connecting the LOADING inductor, 1L10, at the point designated as "A" in Figure 10–22 and bolt them together. Then remove plate voltage from the intermediate power-amplifier by opening the plate lead at some point in the circuit, such as the plate terminal on the exciter modulation transformer (1T6). Close the 250–K P A OVERLOAD breaker (1S5). Then, apply plate voltage to the rest of the exciter and tune the intermediate power-amplifier to resonance by means of the 250–K control marked PLATE.

The approximate setting for this control may be obtained from the intermediate power-amplifier tuning chart. Resonance will be indicated by maximum current on the 250–K OUTPUT CURRENT meter (1M7) and on the 250–K POWER AMP GRID meter (1M4). The intermediate power-amplifier neutralizing control (1L7) should now be adjusted to the point where minimum currents are indicated for the intermediate power-amplifier plate tank and intermediate power amplifier grid circuits. As the neutralizing control is varied, it will be found necessary to readjust the buffer and intermediate power-amplifier plate-tank tuning.

If a noticeable peak on 1M7 and 1M4 is not obtained when tuning over the range of the plate tank inductor (P A PLATE), the setting of the neutralizing tank coil (P A NEUT) is probably near the neutralizing point and it should be changed.

Remove the plate voltage; reconnect the plate voltage lead of the intermediate-power-amplifier; turn the POWER OUTPUT control (1R15) fully counter-clockwise; reapply plate voltage and adjust the 250–K P A PLATE control for minimum plate current as indicated by the 250–K POWER AMP PLATE current meter (1M3).

The two leads to 1L10, previously disconnected, should be replaced and coils 1L10 and 1L11 should be adjusted in accordance with the data of the tuning charts. Apply plate power to the r-f stages in the exciter and adjust the exciter LOADING control to the point that provides maximum power-amplifier grid currents. The grid circuit, consisting of LOADING COIL 1L10, coil 1L11 and the grid tuning capacitor 1CA which is connected across these two coils, should now be tuned to parallel resonance. As this circuit is tuned, it may be found necessary to readjust the 250–K P A PLATE coil (1L9).

If the p-a grid currents are found to be unbalanced when the grid circuit is first tuned to resonance, balance may be obtained by rotating the p-a grid tank coil (1L11) a few turns and then readjusting the LOADING control to obtain the proper grid currents (see table: TYPICAL METER READINGS.)

When the proper loading has been obtained, assuming that the 250–K P A PLATE coil (1L9) has been adjusted for minimum intermediate power-amplifier plate current, the intermediate power-amplifier should then be adjusted for maximum efficiency. This condition does not occur at the point of minimum plate current. It is obtained by making the plate-tank circuit slightly capacitive and then adjusting the 250–K LOADING inductor for the proper output. A few such adjustments may be required to arrive at the point of maximum efficiency.

It is possible to adjust the grid circuit in a manner such that the grids of the power-amplifier are excited in parallel. If the LOADING coil (1L10) is tuned to parallel resonance with the grid coupling capacitor and if there is sufficient reactance in the p-a grid tank coil (1L11), one power-amplifier tube (2V1) will be excited directly and the other tube (2V2) will be excited practically in phase through the p-a grid tuning capacitor (1CA). If this improper adjustment should be obtained, only a slight dip will result when the p-a plate tank coil (2L6) is tuned through resonance. Under this condition, when the p-a grid currents are balanced, changing the setting of 1L11 will have little effect on this balance, i.e., changing the inductance of 1L11 will not unbalance the p-a grid currents.

The transmitter, as shipped from the factory, has capacitor 1C58 (which is connected between the low potential terminal of coil 1L10 and ground) short-circuited by means of a link. This link should be removed when the transmitter is operated at a frequency between 550 and 850 kc. When the transmitter is operated at a frequency between 1050 and 1600 kc, capacitors 1C55 and 1C56 should be connected in series between the low potential terminal of 1L10 and ground. This introduces a capacitive reactance at this point in the p-a grid tank circuit and prevents a parasitic condition from existing in the intermediate power amplifier stage in these two bands. No reactance is required at this point during operation in the frequency band between 700 and 1050 kc.

10–10h. Power-Amplifier Tuning—Initial tuning of the power-amplifier should be performed with only a portion of the normal plate voltage applied. This may be effected by shifting the lead connected to terminal "2900" on the secondary side of the plate transformer (2T7) to tap "1450." After the circuits have been tuned to resonance, the lead should be returned to the "2900" tap.

The magnitude of the d-c voltage available from the power supply varies, depending upon the transformer secondary taps connected, as follows:

Secondary Terminals Used	*Approximate Rectified Voltage (d-c)*
0 and 2900	2650
0 and 2050	1870
0 and 1450	1325
2050 and 2900	780

The number of turns on the tank coil (2L7) should be adjusted as specified in the CAPACITOR AND P-A TANK TAPS CHART. At the lower broadcast frequencies, only a few end turns normally will be shorted out of the circuit. If only one or two turns are left unused, they should be "opened" (instead of shorted) by detaching the end turn from its terminal post inside the coil form) at each end of the coil assembly. The tuning coil (2L6) should be set in its mid-position until the proper taps are found, in order to permit tuning through resonance. The plate tank capacitors, 2C10–11–12–13, should be connected as indicated in the CAPACITOR AND P-A TANK TAPS CHART, utilizing the connectors supplied as MI–7185–10B, C, D. Neutralization is unnecessary since fixed neutralizing capacitors are employed.

The plate caps should now be attached to the four RCA–872 rectifier tubes of the power-amplifier supply.

CAPACITOR AND PA TANK TAPS CHART

Frequency (kc.)

Coil		Capacitor Schematic Symbol	550–700	700–750	750–850	850–1000	1000–1050	1050–1250	1250–1350	1350–1500	1500–1600
Buffer	1L5	—	A	A	A	A	A	B	B	B	B
IPA Neutralizing	1L7	—	C	C	D	D	D	E	E	E	E
IPA Plate Tank	1L9	$1C_B$	F	F	F	G	G	G	H	H	H
PA Grid Coupling	1L10	$1C_C$	I	I	I	J	J	J	K	K	K
PA Grid Tank	1L11	$1C_A$	L	L	M	M	N	N	P	P	Q
PA Plate Tank	2L6	$2C_D$ $2C_B$	R	S	S	S	T	T	T	U	U
Tank Coil Approximate No. of Turns Not Used	2L7		0 to 5	0 to 10	0 to 10	0 to 10	6 to 12	6 to 12	6 to 12	10 to 12	10 to 12

Note: The combinations of capacitors corresponding to the letters in the above chart are given below:

A. 1C17 connected in series with 1C18 and 1C19 in parallel. 1C18 and 1C19 connected from IPA grid to 1C16.
B. 1C17, 1C18 and 1C19 connected in series. 1C19 connected from IPA grid to 1C16.
C. 1C20 and 1C21 connected in parallel.
D. 1C20 and 1C42 connected in parallel.
E. 1C21 connected in series with 1C20 and 1C42 in parallel.
F. 1C54 and 1C57 connected in series.
G. 1C48.
H. 1C49.
I. 1C52 and 1C53 connected in parallel.
J. 1C52.
K. 1C52 and 1C53 connected in series.
L. 1C48 and 1C51 connected in parallel.
M. 1C49 and 1C50 connected in parallel.
N. 1C49 and 1C51 connected in parallel.
P. 1C50 and 1C51 connected in parallel.
Q. 1C48 connected in series with 1C50 and 1C51 in parallel.
R. 2C10 and 2C12 connected in parallel. 2C11 and 2C13 connected in parallel. Connect the two combinations in series.
S. 2C12 and 2C13.
T. 2C10 and 2C11.
U. 2C10 and 2C12 connected in series. 2C11 and 2C13 connected in series. Connect the two combinations in series.

Close the PLATE and PLATE OVERLOAD breakers (2S3 and 2S4, respectively) and with the coupling coil set for least coupling, tune for resonance as indicated by a minimum plate current indication on the P.A. PLATE TOTAL meter (2M5). With minimum coupling to the antenna, the plate current of the final amplifier tubes should be low since the tubes are unloaded.

10–10i. Output Circuit—The variable coupler in the PA plate coil 2L7 is designed to terminate into approximately 40 ohms, and it is necesesary to adjust the T network to match this input impedance and the output load impedance. Electrically, the T network consists of a low-pass filter in which the series arms (2L9, 2L10) are inductive and the parallel section (2C15–2C17) is capacitive. The equivalent circuit is illustrated in Figure 10–23. The portion of each coil to be utilized and the selection of the coupling capacitors (2C15–2C17) will depend upon the resistance and reactance of the antenna or characteristic impedance of the transmission line, and on the operating frequency.

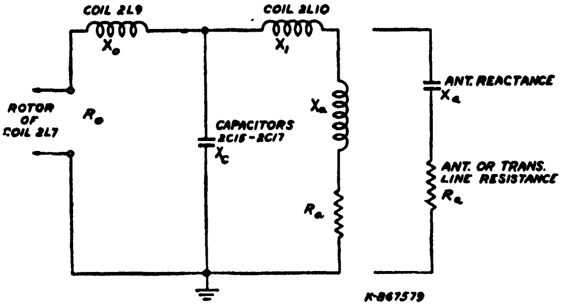

FIG. 10–23. Equivalent output circuit.

The operation of transmitters into different types of load may be classified as follows:

Case 1: Operation directly into an antenna.
Case 2: Operation into an open-wire grounded transmission line.
Case 3: Operation into a concentric transmission line.

The correct values of capacitance and inductance for the respective output networks may be computed by means of the formulae which are explained and illustrated in the following paragraphs.

Case 1. Output Directly into an Antenna:

Let R_o = input impedance of network (approx. 40 ohms)
R_a = resistance of antenna
X_a = reactance of antenna (either inductive or capacitive)

These three quantities have known values. The three quantities to be determined are:

(1) X_o = required inductive reactance of input branch of network (coil 2L9)
(2) X_1 = required inductive reactance of output branch of network (coil 2L10)
(3) X_c = required capacitive reactance of shunt capacitance (capacitors 2C15–2C17)

To be strictly correct, X_o equals the required inductive reactance of the input branch of the network minus the leakage reactance of the coupling coil 2L7. In most cases this leakage reactance is small, and therefore it is neglected in the following description and calculations.

Starting with the output load conditions, the antenna reactance may be highly inductive, only slightly inductive, or capacitive. Since the algebraic sum of X_1 and X_a (hereinafter called X_{an}) must always be inductive but should be held reasonably low, coil 2L10 may be short-circuited when the antenna reactance is highly inductive. If the antenna reactance is only slightly inductive, such as from 0 to 100 ohms, a portion of coil 2L10 should be used to give the output circuit a definite inductive reactance (X_{an}). A good assumed value of X_1 for this purpose is the inductive reactance corresponding to about one-fourth of the total inductance available in the coil, or 25 microhenries. The inductive reactance (X_1) for this value depends upon the operating frequency according to the following table:

Frequency (kc.)	X_1 *(ohms)*
500	78.3
750	117.5
1000	156.6
1250	195.8
1500	234.9
1750	274.1
2000	313.2

If the antenna reactance is capacitive, sufficient turns of coil 2L10 must be used to make the sum of X_1 and X_a (X_{an}) inductive and of a value large enough to provide a definite assurance that the output branch (X_{an}) will never become capacitive due to climatic or other variations. When R_o is greater than R_a, the minimum permissible value of X_{an} is given by:

$$X_{an}\,(\text{min.}) = \sqrt{R_a(R_o - R_a)}\ \text{ohms}$$

Assuming that:

$$Z^2_{an} = R_a^2 + X^2_{an}\ (\text{algebraic values}),$$

then the values of X_o and X_c for correct impedance match may be computed from the following formulas:

$$(1)\ X_o = \sqrt{\frac{R_o}{R_a}(Z^2_{an} - R_aR_o)}\ \text{ohms}$$

$$(2)\ X_c = \frac{Z^2_{an}}{X_{an} + \dfrac{R_aX_o}{R_o}}\ \text{ohms}$$

The value of X_o thus obtained should be checked against the total value available (coil 2L9) as shown in the following table:

Frequency (kc.)	X_0 (ohms)
500	314
750	471
1000	628
1250	785
1500	942
1750	1099
2000	1256

The value of the total shunt capacitance (2C15–2C17) may be calculated from the equation:

$$C = \frac{10^3}{6.28 \times f \times X_r} \text{ microfarads}$$

(X_r found from Eq. (2) above)

where C = capacitance in microfarads
f = operating frequency in kilocycles

The values of the capacitors 2C15, 2C16, and 2C17 in various parallel and series combinations, and alone are given in the following table:

	Capacitance ($\mu\mu f$)	Combination
A	5300	2C15, 2C16 and 2C17 in parallel.
B	4500	2C15 and 2C16 in parallel—2C17 is not used.
C	3800	2C15 and 2C17 in parallel—2C16 is not used.
D	3000	2C15 alone - 2C16 and 2C17 are not used.
E	2300	2C16 and 2C17 in parallel—2C15 is not used.
F	1500	2C16 alone—2C15 and 2C17 are not used.
G	1000	2C15 and 2C16 in series—2C17 is not used.
H	800	2C17 alone -2C15 and 2C16 are not used.
I	630	2C15 and 2C17 in series—2C16 is not used.
J	520	2C16 and 2C17 in series—2C15 is not used.
K	445	2C15, 2C16 and 2C17 in series.

When properly adjusted, the antenna current (I_a) should be very close to the value determined by the equation:

$$I_a = \sqrt{\frac{W}{R_a}} \text{ amperes}$$

where W = expected power output in watts
R_a = antenna resistance in ohms

As an illustrative example of the foregoing calculations for Case 1, it is assumed that the power output (W) is 1000 watts, the antenna characteristics ($R_a + jX_a$) are $25 + j34$, and the operating frequency (f) is 1250 kc. The known values are:

R_o (network input impedance) = 40 ohms
R_a (antenna resistance) = 25 ohms
X_a (antenna reactance) = $+j34$ ohms

Since the antenna is only slightly inductive, about one-fourth of the inductive reactance of coil 2L10 should be used as a trial value. At 1250 kc, the table shows that this inductive reactance (X_1) is approximately equal to 196 ohms.

Then

$$X_{an} = X_1 + X_a = 196 + 34 = 230 \text{ ohms}$$

The minimum permissible value of X_{an} is:

$$X_{an} \text{ (min.)} = \sqrt{25(40 - 25)} = \sqrt{375} = 19.4 \text{ ohms}$$

This indicates that the above selection of X_1 is amply large and probably should be reduced if a recalculation becomes necessary. Proceeding to determine X_o and X_c, we have:

$$Z^2_{an} = 25^2 + 230^2 = 53{,}525$$

Then

$$X_o = \sqrt{\frac{40}{25}[53{,}525 - (25 \times 30)]}$$

$$= \sqrt{1.6 \times 52{,}775} = \sqrt{84{,}440} = 290 \text{ ohms}$$

Checking this value against the total available (coil 2L9) as shown in the tabulation, it is found that the maximum inductive reactance at 1250 kc is 785 ohms. Therefore, the preceding value of 290 ohms (approximately one-third of 2L9) is satisfactory for X_o.

$$X_c = \frac{53{,}525}{230 + \left(\frac{25}{40} \times 290\right)} = \frac{53{,}525}{230 + 182}$$

$$= \frac{53{,}525}{412} = 130 \text{ ohms}$$

$$C = \frac{10^3}{6.28 \times 1250 \times 130} = \frac{1}{1020}$$

$$= .00098\ \mu f = 980\ \mu\mu f$$

Referring to the table of capacitor values it will be seen that the combination G (1000 $\mu\mu f$) comes nearest to the value required.

The antenna current

$$(I_a) = \sqrt{\frac{1000}{25}} = \sqrt{40} = 6.32 \text{ amperes}$$

(no modulation).

Case 2. Output into an Open-Wire Grounded Transmission Line:

A four-wire or six-wire transmission line with two or four wires grounded is the most usual form of Case 2. Such a line will have an impedance of approximately 235 ohms when constructed according to RCA recommended specifications.

The calculation for the value of the shunt capacitors (2C15–2C17) and for the adjustment of coils 2L9 and 2L10 is the same as for Case 1, substituting the known surge impedance, 235 ohms, of the transmission line for R_a and letting $X_a = 0$. Care must be exercised in terminating the antenna end of the transmission line into its own impedance, so that no standing waves will appear on the line itself.

Therefore:

$$X_{an} = X_1 + X_a = X_1 + 0 = X_1$$

where X_1 = inductive reactance of coil 2L10
X_a = transmission line reactance, which should always be zero

Assuming the characteristic impedance of the transmission line to be 235 ohms, the known values are:

R_o = input impedance of network (approx. 40 ohms)
R_a = transmission-line impedance = 235 ohms
X_a = transmission-line reactance = 0

The three quantities to be determined are:

(1) X_o = required inductive reactance of the input branch of the network, coil 2L9.
(2) X_1 = required inductive reactance of the output branch, coil 2L10.
(3) X_c = required capacitive reactance of the shunt capacitance, capacitors 2C15–2C17.

Starting with the output load conditions, the transmission line is considered as a pure resistance, whence:

$$X_a = 0, \qquad \text{and} \qquad X_{an} = X_1$$

From the formula for the minimum permissible value of X_{an}:

$$X_1\,(\text{min.}) = \sqrt{R_a(R_o - R_a)} \text{ ohms}$$

it is evident, since R_o is less than R_a, that coil 2L10 may be short-circuited. However, it is usually advisable to use a few turns of the coil to aid in suppressing harmonic radiation. As before, a good assumed value for X_1(2L10) for this purpose is the inductive reactance corresponding to about 25 microhenries of inductance. Then

$$Z^2_{an} = R_a^2 + X_1^2$$

and:

$$X_o = \sqrt{\frac{R_o}{R_a}\,(Z^2_{an} - R_aR_o)} \text{ ohms}$$

$$X_c = \frac{Z^2_{an}}{X_1 + \dfrac{R_aX_o}{R_o}} \text{ ohms}$$

$$C = \frac{10^3}{6.28 \times f \times X_c} \text{ microfarads}$$

where C = shunt capacitance in microfarads
f = operating frequency in kilocycles

The transmission line current is:

$$I_a = \sqrt{\frac{W}{R_a}} \text{ amperes}$$

where W = expected power output in watts
R_a = characteristic impedance of transmission line in ohms

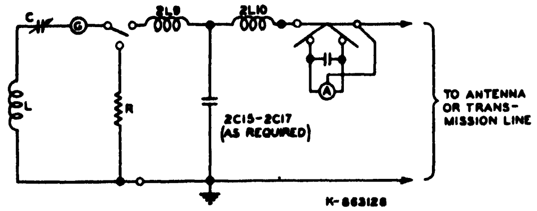

FIG. 10–24. Output test circuit.

As an illustration of Case 2, it is assumed that the power output (W) is 1000 watts, the transmission line has a characteristic impedance (R_a) of 235 ohms, and the operating frequency (f) is 1250 kc.

$$Z^2_{an} = 235^2 + 196^2 = 55{,}225 + 38{,}416 = 93{,}641$$

Then

$$X_o = \sqrt{\frac{40}{235}\,(93{,}641 - 9400)} = \sqrt{14{,}320} = 120 \text{ ohms}$$

$$X_c = \frac{93{,}641}{196 + \left(\dfrac{235}{40} \times 120\right)} = \frac{93{,}641}{901} = 104 \text{ ohms}$$

$$C = \frac{10^3}{6.28 \times 1250 \times 104} = \frac{1}{816} = 1225\ \mu\mu\text{f}$$

This value may be obtained approximately by connecting capacitor 2C15 in series with the capacitor (2C16), for a total of 1000 $\mu\mu$f. (Combination G on capacitor table.)

Thus an impedance match for this assumed illustration of Case 2 may be obtained by using approximately one-fourth of the reactance of coil 2L10, one-seventh of the reactance of coil 2L9, and capacitors 2C15 and 2C16 in series.

The transmission line current for zero modulation is:

$$I_a = \sqrt{\frac{1000}{235}} = \sqrt{4.26} = 2.06 \text{ amperes}$$

At 100-percent modulation, this would increase to·

$$2.06 \times 1.22 = 2.52 \text{ amperes}$$

It is advisable to check the accuracy of the foregoing calculations by computing the r-f voltage across the shunt capacitors, from both the input and the output circuits. If the two calculations give identical results, a perfect impedance match has been obtained.

From the output load circuit:

$$\begin{aligned} E_c &= \sqrt{(I_aR_a)^2 + (I_aX_1)^2} \\ &= \sqrt{(2.06 \times 235)^2 + (2.06 \times 196)^2} \\ &= \sqrt{397{,}500} = 630 \text{ volts} \end{aligned}$$

From the input circuit:

$$I_o = \sqrt{\frac{1000}{40}} = \sqrt{25} = 5 \text{ amperes}$$

$$\begin{aligned} E_o &= \sqrt{(I_oR_o)^2 + (I_oX_o)^2} \\ &= \sqrt{(5 \times 40)^2 + (5 \times 120)^2} \\ &= \sqrt{400{,}000} = 632 \text{ volts} \end{aligned}$$

Case 3. Output into a Concentric Transmission Line:

The two rotor terminals of coil 2L7 may be connected directly to the two terminals of this transmission line with approximately 0.002 μf in series. It is recommended, however, that the concentric transmission line be connected identically as in Case 2 for the open-wire grounded line, thus obtaining attenuation of harmonic radiation in the T network.

When connected in this manner, the calculation of values for impedance match is the same as for Case 2, using the characteristic impedance of the concentric line (70 ohms) for R_o, instead of the higher value of 235 ohms for an open-wire grounded line.

The values of capacitance and inductance determined as above should be applied to the network and final adjustments made with the aid of an r-f bridge connected to the input of the network. If a bridge is not available, the following substitution method may be used in adjusting the input resistance of the network (R_o) to 40 ohms, and the output to the impedance of the antenna or transmission line.

10–10j. Output Adjustment—Referring to Figure 10–24, the coil, L, should be loosely coupled to a low-power source of radio frequency. Only sufficient power to afford a readable deflection on the thermo-galvanometer, G, is necessary. It is desirable that the test circuit be shielded and wired in such a manner that stray capacities are reduced to a minimum. The test resistor, R, should be a non-inductive, 40 ohm resistor capable of dissipating about five watts. The calculated value of shunt capacitance should be connected in the circuit and adjustments made as follows:

First, throw the switch to the resistor position and adjust capacitor C for maximum current indication. Note the capacitor dial and current readings. If the maximum current indication is too low for accurate observation, increase the coupling slightly.

Shift the switch to the network position and vary the taps of inductor 2L10 until a point is found at which the galvanometer reading is the same as that previously observed when capacitor C is tuned for maximum indication.

When this adjustment has been completed, adjust the taps of 2L9 to a point which gives maximum current indication for the setting of capacitor C used with the switch in the resistance position. Finally, repeat the procedure again and make slight adjustments of 2L9 and 2L10 as required.

A value of X_0 slightly smaller than that calculated must be used to "tune out" the coupling coil inductance. This value can best be determined by inserting a low range r-f ammeter in the input arm of the network, and with very loose coupling and the lowest plate voltage applied, reducing the inductance of 2L9 until the maximum current point is reached.

When the output circuit has been properly adjusted, full plate voltage may be applied and the coupling adjusted for the normal power output as indicated by the antenna ammeter. When the transmitter is to be operated at two output powers, all adjustments should be made at the higher power.

When the antenna network has been properly adjusted, the exciter POWER OUTPUT control (1R15) should be rotated until the amplifier grid current meters indicate their recommended value. The grid currents of the two power-amplifier tubes should be balanced, but if not, a slight adjustment of inductors 1L10 and 1L11 will bring them into balance. Check all r-f stage meter readings against the TYPICAL METER READINGS table and make whatever adjustments are necessary.

The power output of the final amplifier may be varied by means of the 1-K POWER OUTPUT control (2L7) if, for any reason, the antenna resistance varies and changes the transmitter load.

When the proper loading has been obtained, assuming that the 1-K PA PLATE variable inductor (2L6) has been adjusted for minimum power-amplifier plate current, the power-amplifier should be adjusted for maximum efficiency. This condition does not occur at the point of minimum plate current. It is obtained by making the plate-tank circuit slightly capacitive and then adjusting the coupling for the proper output. Since there are four positions of the coupling coil (2L7) that give the same degree of coupling, each of these positions should be tried. It may be found that with the grid currents of the power-amplifier tubes balanced, the plate currents may be slightly unbalanced. This unbalance will usually vary with each of the four positions of the coupling coil. The position which gives the maximum efficiency will usually result in the best balance. It may be necessary then to unbalance the location of the taps on the two sides of the power-amplifier tank coil (2L6) slightly in order to completely balance the power-amplifier tubes.

A cathode resistor is provided in the cathode circuit of each power output tube in order to keep the plate currents of these tubes within the maximum rated value when plate voltage is applied in the absence of excitation. These resistors (2R3, 2R4) are provided with taps. The 250-K PLATE breaker should be opened and the 1-K PLATE breakers should be closed, thus applying plate voltage to the power-amplifier tubes with no excitation at the grids. The tap to be used is that which inserts sufficient resistance in the cathode circuits to keep the power dissipation of each tube just under 300 watts. Plate voltage and current for each tube are indicated by the panel meters.

A pickup coil (2L8), which supplies excitation to the modulation indicator, is coupled to the coil (2L7). It may be necessary to remove turns from this coil to obtain sufficient excitation to the modulation indicator. The effect is to resonate the inductance of the coil with the capacitance of the connecting cable. This adjustment is rather critical and turns should be removed from the coil one at a time. While the adjustment is being made, the coil should be in the position for maximum coupling. After maximum output is obtained, the coupling may be adjusted to the desired value by rotating the coil on its mounting.

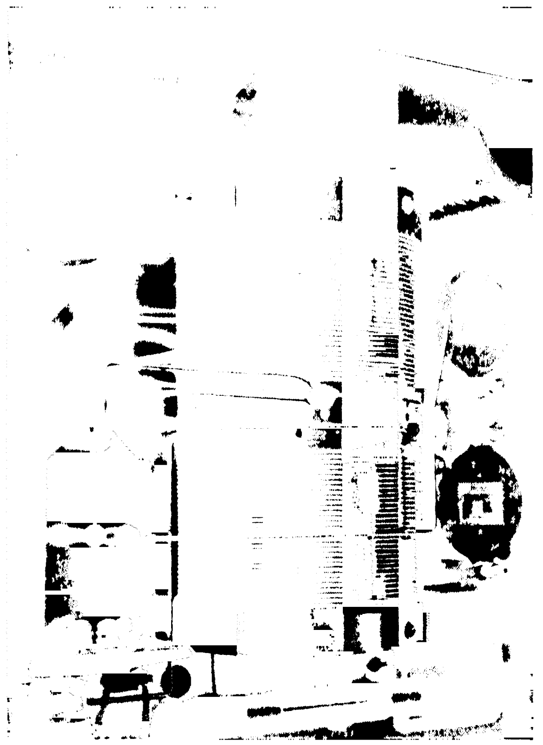

FIG. 10–25. The tank coil in the 1-K is a high Q inductor. Variable inductive coupling is employed which provides an extremely simple arrangement for coupling the load to the power amplifier tank circuit.

10–10k. Modulator Adjustment—When the r-f stages have been correctly adjusted for normal operation, close the second audio stage plate breaker, 250–K MOD. OVERLOAD (1S6). (Be sure that the modulator breaker 1–K MOD. OVERLOAD (2S9) is open before closing 1S6. Leave breaker 2S9 open during this adjustment.) The tubes should not draw plate current with the grid bias potentiometer set as previously indicated. These potentiometers (1R22 and 1R54) should now be adjusted so that the sum of the plate and screen-grid currents (which is what is actually indicated on the plate current meters) for each of the second audio stage tubes is 100 ma. The designations LEFT and RIGHT on the meters refer to the tubes as viewed from the front of the transmitter. Taps are provided on the bleeder resistors (1R62 and 1R63), in order that the screen and suppressor voltages of the tubes may be changed when necessary. *Caution.* Open 1S6 before proceeding.

Inspect the safety gaps on the primary of 2T4. These gaps should have a spacing of 0 050 inch and should always be kept well polished. Next, the grid bias of the modulator tubes should be set by closing the MOD. OVERLOAD breaker 2S9 (be sure 1S6 is open before closing 2S9) and adjusting the MODULATOR BIAS potentiometers 2R16 and 2R17 for plate current as indicated in the table of TYPICAL METER READINGS. Approximately 90 volts should be available across the modulator bias rectifier bleeder (2R18). This voltage may be measured across capacitor 2C20 or 2C21.

Since the inverse feed-back is connected externally between the two units, it is quite possible that the polarity of this feed-back has been reversed in these connections. It is necessary to check this as follows: Reduce the plate voltage on the modulators by moving the tap connection on the plate transformer (2T7) from tap "2900" to tap "1450." Turn on the transmitter, but do not close the two MOD. OVERLOAD breakers (1S6 and 2S9). Next, close the 250–K MOD. OVERLOAD breaker. Then, observing the modulator plate current meters, close the modulator breaker (2S9). If the indicated modulator plate current is low (between 0 and 50 ma per tube) then the feed-back polarity is correct. However, if the indicated plate current is high (150–300 ma per tube) then the audio system is oscillating, and the feed-back polarity must be reversed. To do this, reverse the twisted pair going to terminals 19 and 20 on terminal board "B" in the exciter unit. Then recheck for oscillation by turning on the transmitter and closing the audio overload breakers. The plate current should no longer rise excessively. Restore the plate voltage to normal value. With correct feed-back polarity, there should be no appreciable change in the no-signal value of the modulator plate current when the 250–K MOD. OVERLOAD breaker is opened and closed. If necessary, readjust the bias controls for the drivers (RCA–828) and modulators (RCA–833–A) for the correct static (unmodulated) plate currents as indicated in the table TYPICAL METER READINGS. (When the transmitter is set up for straight 500-watt operation, it is not necessary to reduce further the plate voltage when checking the feed-back polarity.)

10–10l. Operation—After the transmitter has been tuned to the operating frequency and the other adjustments just described have been completed, the

TYPICAL METER READINGS
EXCITER

Line Voltage 110 Volts

Tube	E_p (volts)	I_p (ma)	E_g (volts)	I_g (ma)	E_{sg} (volts)	E_{sup} (volts)
Crystal Oscillator	240	15–18			160	
Buffer	1250	60–70			210	65
Intermediate Power-Amplifier	1500	180–205		45–60		
1st Audio	270	*7–8			160	
2nd Audio	780	80–100	–73		690	65
(per tube)					670–690	

Plate Tank (Output) Current—2.0 to 4.5 amp

* This value includes screen current.

TYPICAL METER READINGS
AMPLIFIER

Line Voltage 230 Volts

Tube	1000 Watts	500 Watts Power Change Panel	500 Watts Straight	250 Watts Power Change Panel (250/500)	250 Watts Power Change Panel (250/500)
Grid Current (ma per tube)	95	1000	100	100	100
Amplifier Plate Current (ma total)	550	403	403	286	286
Amplifier Plate Voltage (volts)	2450	1770	1770	1250	1250
* Modulator Plate Voltage (volts)	2550	2600	1850	1850	2600
Modulator Plate Current (ma) (100 per cent modulation)	210	160	185	115	100
Modulator Plate Current (ma) (0 per cent modulation)	50	50	45	48	50
* Modulator Grid Voltage (volts)	61	61	40	40	61

* Must be measured with an external meter

equipment is ready for operation. In normal use, with the transmitter shut down, the following breakers should be in their closed position: 1S1, 1S2, 1S5, 1S6, 2S2, 2S4 and 2S9.

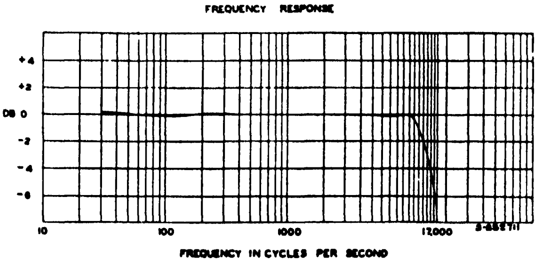

FIG. 10–26. This curve taken at 25-percent modulation indicates the high-frequency cutoff obtained in the output circuits of modulator in order to reduce adjacent channel interference.

1. *To Place the Transmitter in Operation.* The following operations should be performed, in the order listed:

(a) Close the 1-K LINE breaker.
(b) After the time delay relay has operated, close the 250-K PLATE breaker.
(c) Close the 1-K PLATE breaker.
(d) Adjust the 1-K LINE VOLTAGE control for 230 volts.
(e) Adjust the POWER OUTPUT control, if necessary, for correct antenna current.

2. *To Shut Down the Transmitter.* The following operations should be performed in the order listed:

(a) Open the 1-K PLATE breaker.
(b) Open the 250-K PLATE breaker.
(c) Open the 1-K LINE breaker.

10–10m. Maintenance—With ordinary care, little attention will be required to keep this transmitter in operation. However, to avoid program

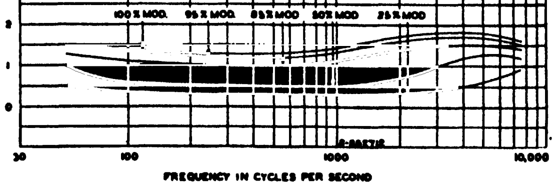

FIG. 10–27. Distortion has been reduced to low levels in the 250-K.

interruption through failure in the transmitter, a regular schedule of inspection should be established.

It is important that the transmitter be kept free from dust and for this purpose a small electric hand-blower may be used to advantage.

The transmitter should be inspected periodically for poor contacts and loosened connections. At such times, each contact of every switch and relay should be inspected and cleaned. The contacts should be cleaned with carbon tetrachloride applied with a soft brush. A *small* amount of vaseline should be applied to the contacts of the door-interlock switches after they have been cleaned. All r-f and ground connections should be kept tight.

A regular check should be made of all tubes in the transmitter. Each tube should be inspected and tested immediately upon its receipt, to make certain that no damage has been caused by shipment. So far as possible, tube failure should be anticipated by keeping a log of tube life. All meter readings should be recorded and checked against readings previously taken.

When a rectifier tube is replaced in the transmitter, make certain, before placing the equipment in operation, that the new tube has been properly "aged." The procedure is described under *preliminary adjustments.* Spare rectifier tubes may be aged before they are stored. If they are then stored in an upright position and are not subsequently jarred, the initial warm-up period when they are placed in service may be reduced to approximately one minute.

The external appearance of the transmitter may be kept like new by judicious applications of the matching lacquers, which are included as a part of the equipment.

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CHAPTER 11

FM BROADCAST TRANSMITTERS

Frequency-modulated broadcast stations in the United States operate in a frequency band extending from 88 to 108 megacycles. Each F-M broadcast channel in this band is 200 kc wide. The channels start at 88.1 mc and continue in steps of 200 kc up to and including 107.9 mc, resulting in a total of 100 usable F-M broadcast channels.

11-1. Definitions—The following definitions, peculiar to frequency modulation, have been taken from the F.C.C. "Standards of Good Engineering Practice Concerning F-M Broadcast Stations":

1. *FM broadcast station*—The term "FM broadcast station" means a station employing frequency modulation in the FM broadcast band and licensed primarily for the transmission of radiotelephone emissions intended to be received by the general public.

2. *Frequency modulation*—The term "frequency modulation" means a system of modulation where the instantaneous radio frequency varies in proportion to the instantaneous *amplitude* of the modulating signal (amplitude of modulating signal to be measured after pre-emphasis, if used) and the instantaneous radio frequency is independent of the *frequency* of the modulating signal.

3. *FM broadcast band*—The term "FM broadcast band" means the band of frequencies extending from 88 to 108 megacycles, which includes those assigned to noncommercial educational broadcasting.

4. *Center frequency*—The term "center frequency" means:

(a) The average frequency of the emitted wave when modulated by a sinusoidal signal.
(b) The frequency of the emitted wave without modulation.

5. *Frequency swing*—The term "frequency swing" means the instantaneous departure of the frequency of the emitted wave from the center frequency resulting from modulation.

6. *FM broadcast channel*—The term "FM broadcast channel" means a band of frequencies 200 kilocycles wide and is designated by its center frequency. Channels for FM broadcast stations begin at 88.1 megacycles and continue in successive steps of 200 kilocycles to and including 107.9 megacycles.

7. *Antenna field gain*—The term "antenna field gain" of an FM broadcast antenna means the ratio of the effective free space field intensity produced at one mile in the horizontal plane expressed in millivolts per meter for 1 kilowatt antenna input power to 137.6 mv/m.

8. *Free space field intensity*—The term "free space field intensity" means the field intensity that would exist at a point in the absence of waves reflected from the earth or other reflecting objects.

9. *Multiplex transmission*—The term "multiplex transmission" means the simultaneous transmission of two or more signals within a single channel. Multiplex transmission as applied to FM broadcast stations means the transmission of facsimile or other signals in addition to the regular broadcast signals.

10. *Percentage modulation*—The term "percentage modulation" as applied to frequency modulation means the ratio of the actual frequency swing to the frequency swing defined as 100 percent modulation, expressed in percentage. For FM broadcast stations, a frequency swing of ±75 kilocycles is defined as 100 percent modulation.

11. *Effective radiated power*—The term "effective radiated power" means the product of the antenna power (transmitter output power less transmission line loss) times (a) the antenna power gain, or (b) the antenna field gain squared.

12. *Service area*—The term "service area" as applied to FM broadcasting means the service resulting from an assigned effective radiated power and antenna height above the average terrain.

13. *Antenna height above average terrain*—The term "antenna height above average terrain" means the average of the antenna heights above the terrain from two to ten miles from the antenna. (In general a different antenna height will be determined by each direction from the antenna. The average of these various heights is considered as the antenna height above the average terrain.)

11-2. Location of FM Transmitters—Due to the fact that the transmission characteristics of the very high frequencies employed in F-M broadcasting resemble the characteristics of visible light in many ways, some of the considerations in selecting a transmitter site differ considerably from those involved in selecting a site for a broadcast transmitter operating in the standard broadcast band. A site for an F-M transmitter should be chosen with the following factors in mind:

1. An F-M transmitter should be centrally located in the area to be served. It is usually desirable that the location be close to the business and factory areas of the principal city in the service area as this results in a strong signal intensity being produced in these areas where a high noise level, due to local electrical disturbances, exists.

2. The transmitting antenna should be at the highest possible elevation; higher than all surrounding buildings, hills, and other obstructions in order to reduce "shadow" effects to a minimum. Antenna height is important because of the quasi-optical nature of the very high frequencies which makes it important that the location provide "line-of-sight" over the entire area being served.

3. The transmitter must be at a location which is accessible at all times of the year; adequate space must be available for the equipment, keeping in mind the possibility of future increases in power; and services such as power and telephone lines must be available.

The transmitter locations listed below have all proven satisfactory in individual cases and all are in present-day use; however, careful study is necessary for each specific installation in order that the most satisfactory of a number of possible sites may be chosen.

1. Locations on top of a tall building in the business area of the city being served. Such a location has the advantage that the strongest signal intensity is delivered in the business and manufacturing areas where the electrical noise level is usually the greatest. It is important that the building be capable of accommodating the desired type of transmitting antenna.

2. Locations on a high hill or mountain overlooking the desired service area. Such a location must be reasonably close to the city, otherwise the signal intensity from such a site may not compare favorably with competitive stations located within the city. The advantage of such a location is the height it affords, but an installation of this nature may prove quite expensive.

3. Location of the F–M transmitter in the same building with an existing standard broadcast transmitter, with the F–M antenna mounted atop one of the A–M towers. An installation of this nature is possible when the F–M and A–M transmitters are under the same ownership. It has the advantage of low installation cost, but the disadvantage that the site may not be the best for good F–M coverage.

4. Locations where the F–M antenna is mounted on a tall tower erected expressly for this purpose either on a building of medium height or resting directly on the ground. Such an installation is often employed when none of the other sites is available. Although rather expensive, it is effective in gaining the desired antenna height.

11–3. Service Area of F–M Broadcast Stations—Although some F–M service may occasionally be provided by tropospheric waves, the service area of an F–M broadcast transmitter is considered to be only that served by the ground wave. The extent of the service is determined by the point at which the ground wave is no longer of sufficient intensity to provide satisfactory broadcast service. The field intensity considered necessary for satisfactory broadcast service in city, business, or factory areas is 1000 microvolts per meter, while in rural areas a field intensity of 50 microvolts per meter is considered satisfactory.

11–4. Antenna Systems—It is standard practice in F–M broadcasting to employ horizontal polarization. The transmitting antenna is usually nondirective in a horizontal plane; however, inasmuch as practically all receiving installations lie within a few degrees of the horizon, it is often desirable to employ a transmitting antenna which directs the radiation toward the horizon. Such an antenna results in a considerable increase in "effective radiated output"[1] and makes it possible to achieve a given output power level with a transmitter of considerably lower output rating. F–M transmitting antennas of this type are described in Chapter 17.

In many cases the savings in initial transmitter cost and transmitter operating expense more than justify the cost of such a directive transmitting antenna; however, every installation is an individual case, and it is necessary to compare the cost of transmitters of various output power ratings with the cost of antennas of various directional effectiveness in order to determine the most economical combination.

11–5. The F–M Transmitter Plant—An F–M broadcast transmitter plant, in addition to a suitable transmitter and transmitting antenna, should also contain the following facilities:

1. Audio input equipment similar to that described in the preceding chapter. The local origination facilities may be omitted in the event that the studios and transmitter are located in the same building. A peak-limiting amplifier is just as effective in an F–M system and should be included in the audio facilities.

2. A regular and emergency supply of a-c power.

3. Measuring equipment capable of measuring the transmitter frequency, percentage of modulation, response-frequency characteristics, harmonic distortion and noise level.

It is usually convenient to mount all the amplifiers and measuring equipment in cabinet type relay racks and extend all the audio and transmitter operating controls and indicating devices to a conveniently located control console. In this way, complete control of the plant may be achieved from a central operating point.

11–6. Performance Requirements for F–M Broadcast Systems—The following performance requirements have been extracted from the F.C.C. "Standards of Good Engineering Practice Concerning F–M Broadcast Stations" and outline the general performance standards required for this type of broadcast service. Additional F.C.C. rules and regulations governing the operation of F–M broadcast stations are given in Chapter 19.

1. *Electrical Performance Standards.* The general design of the FM broadcast transmitting system (from input terminals of microphone pre-amplifier, through audio facilities at the studio, through lines or other circuits between studio and transmitter, through audio facilities at the transmitter, and through the transmitter, but excluding equalizers for the correction of deficiencies in microphone response) shall be in accordance with the following principles and specifications:

(a) The transmitting system shall be capable of transmitting a band of frequencies from 50 to 15,000 cps. Pre-emphasis shall be employed in accordance with the impedance-frequency characteristic of a series inductance-resistance network having a time constant of 75 microseconds. (See Figure 11–1.) The deviation of the system response from the standard pre-emphasis curve shall lie between two limits as shown in Figure 11–1. The upper of these limits shall be uniform (no

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[1] "Effective radiated power" is the actual power delivered to the antenna multiplied by the power gain of the antenna in the direction of the horizon.

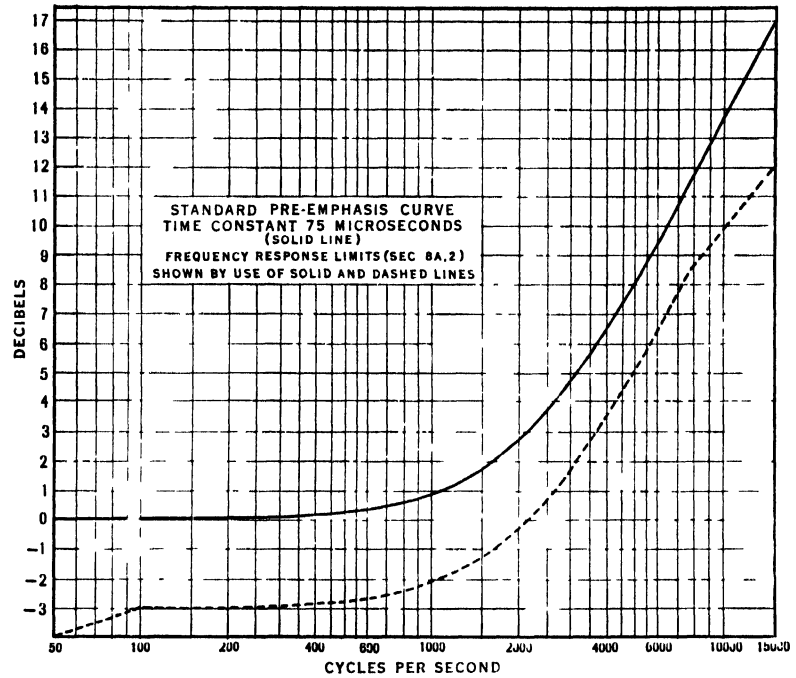


Fig. 11–1 Standard pre-emphasis curve for F-M broadcast stations.

deviation) from 50 to 15,000 cps. The lower limit shall be uniform from 100 to 7500 cps, and three db below the upper limit; from 100 to 50 cps the lower limit shall fall from the three db limit at a uniform rate of one db per octave (four db at 50 cps); from 7500 to 15,000 cps the lower limit shall fall from the three db limit at a uniform rate of two db per octave (five db at 15,000 cps).

(b) At any modulation frequency between 50 and 15,000 cps and at modulation percentages of 25%, 50%, and 100%, the combined audio frequency harmonics measured in the output of the system shall not exceed the root-mean-square values given in the following table:

Modulating Frequency	*Distortion*
50 to 100 cps	3.5%
100 to 7500 cps	2.5%
7500 to 15,000 cps	3.0%

Measurements shall be made employing 75 microsecond de-emphasis in the measuring equipment and 75 microsecond pre-emphasis in the transmitting equipment, and without compression if a compression amplifier is employed. Harmonics shall be included to 30 kc.

It is recommended that none of the three main divisions of the system (transmitter, studio to transmitter circuit, and audio facilities) contribute over one half of these percentages since at some frequencies the total distortion may become the arithmetic sum of the distortions of the divisions.

(c) The transmitting system output noise level (frequency modulation) in the band of 50 to 15,000 cps shall be at least 60 db below the audio frequency level representing a frequency swing of ± 75 kilocycles. The noise-measuring equipment shall be provided with standard 75 microsecond de-emphasis; the ballistic characteristics of the instrument shall be similar to those of the standard VU meter.

(d) The transmitting system output noise level (amplitude modulation) in the band of 50 to 15,000 cps shall be at least 50 db below the level representing 100-percent amplitude modulation. The noise-measuring equipment shall be provided with standard 75 microsecond de-emphasis; the ballistic characteristics of the instrument shall be similar to those of the standard VU meter.

(e) Automatic means shall be provided in the transmitter to maintain the assigned center frequency within the allowable tolerance (± 2000 cps).

(f) If a limiting or compression amplifier is employed, precaution should be maintained in its connection in the circuit due to the use of pre-emphasis in the transmitting system.

2. *Interference Standards.* Field intensity measurements are preferable in predicting interference between FM broadcast stations and should be used, when available, in determining the extent of interference. In lieu of measurements, the interference should be predicted in accordance with the method described herein.

Objectionable interference is considered to exist when the interfering signal exceeds that given by the ratios of the following table. In this table, the desired signal is the median field and the undesired signal is the tropospheric signal intensity exceeded for 1% of the time.

Channel Separation	*Ratio of Desired to Undesired Signals*
Same channel	10:1
Adjacent channel (200 kc removed)	2:1

Objectionable interference is not considered to exist when the channel separation is 400 kc or greater. Accordingly, FM broadcast stations in the same city or same area may be assigned channels 400 kc apart. In the assignment of FM broadcast facilities, the Commission will endeavor to provide the optimum use of the channels in the band, and accordingly may assign a channel different than that requested in an application.

3. *Operating Power: Determination and Maintenance.* The operating power of FM broadcast stations shall be determined by the indirect method. This is the product of the plate voltage (E_p) and the plate current (I_p) of the last radio stage, and an efficiency factor, F; that is:

$$\text{Operating power} = E_p \times I_p \times F$$

The efficiency factor, F, shall be established by the transmitter manufacturer for each type of transmitter for which he requests F.C.C. approval, and shall be shown in the instruction books supplied to the customer with each transmitter. In the case of composite equipment the factor F shall be furnished to the Commission by the applicant along with a statement of the basis used in determining such factor.

The operating power shall be maintained as near as practicable to the authorized operating power, and shall not exceed the limits of 5 percent above and 10 percent below the authorized power except in emergencies. In the event it becomes impossible to operate with the authorized power, the station may be operated with reduced power for a period of 10 days or less provided the Commission and the Inspector-in-Charge of the district in which the station is located shall be notified in writing immediately thereafter and also upon the resumption of normal operating power.

11–7. F–M Transmitters—The representative commercial transmitting equipments described in the remainder of this chapter are designed to perform in accordance with good engineering practice. The method of accomplishing modulation, as well as the method of maintaining a stabilized frequency, differ. Most of the material covering these transmitters has been taken directly from the material supplied by the manufacturer and has been modified only to the extent necessary to adapt it to the text of this book.

11–8. Westinghouse 1- and 3-Kw F-M Transmitter.—In this new Westinghouse F–M transmitter, a new idea in F–M control circuits that offers advantages in broadcast dependability and fidelity is employed. Another improvement is found in the audio circuit. To place the transmitter in operation, it is only necessary to connect the audio input, r-f transmission line, and input power supply. Higher powers may be obtained by adding amplifiers to the basic unit. At the top of the front panel, at convenient eye level, are six large 270° scale meters with special wide blade pointers.

From top to bottom on the front panel are (1) a hinged window that lifts up and locks in open position, thus allowing easy access to the low voltage regulator, driver, and power amplifier tubes; (2) access to the control panel by means of a door which folds up out of the way in such a manner that only the inside finish is exposed to the accidental dropping of tools or continued wear, thus the exterior finish is protected; (3) two lower doors give complete access to the removable oscillator-driver-audio unit and frequency control unit, power switches and relays. A glass panel allows visual inspection of the high voltage rectifier tubes whenever desired.

The oscillator-driver-audio and center-frequency control units are built on standard relay rack chassis and are equipped with plug-in connectors to allow easy removal. Additional center-frequency control and oscillator-driver-audio units may be purchased as spare equipment.

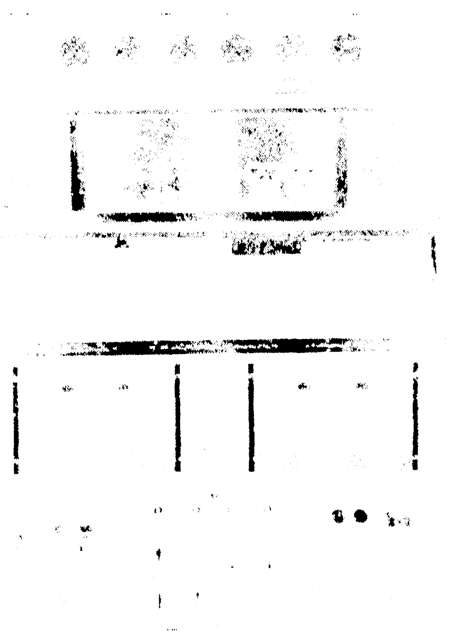


Fig. 11–2. Front view of Westinghouse 1- and 3-kw F-M broadcast transmitter showing accessibility to tubes and back of control panel.

11–8a. Features

1. Single tuning control adjusts center frequency; one meter indicates correct center frequency alignment.
2. Frequency modulation is obtained in a simple circuit using condensers, resistors and nonmicrophonic diode tubes.
3. Center-frequency control established by crystal-controlled pulse-counting circuit. Only two factory-set, noncritical adjustments required.
4. R-f carrier is generated, multiplied and amplified in five simple steps. Cathode-input, grounded grid, triode power amplifier provides screen-grid tube stability.
5. Long-life transformers are operated under low-temperature Class A conditions. Glass tape covered wires and mica insulation.
6. Controls, indicating instruments, and lamps are centrally located on the front panel. All tubes are accessible from front of transmitter.
7. Only eight r-f tank circuit tuning adjustments in the entire transmitter.

8. Forced-air cooling of power amplifier accomplished by a blower whose air intake is equipped with cleanable air filter.

9. R-f driver and power amplifier stages are neutralized by two noncritical adjustments. All important circuits contain individual indicating instruments. No meter-switching is used.

10. Standard commercial type tubes used throughout; all tubes operated below rated plate voltage to provide high reliability and economy.

11. Blocking condenser used in shunt-fed power amplifier is ¼ wave length, open-circuit transmission line, concentric with the plate, concentric-line type, tank circuit.

12. Adjustment of r-f driver grid and plate, power amplifier cathode and plate, and antenna coupling circuits accomplished by motor-drive tuning.

13. Continuously variable power amplifier plate voltage allows power output to be varied from 25% to 125% of rated value.

11–8b. Schematic Diagram—A simplified schematic diagram of the 1 kw F–M transmitter is shown in Figure 11–3.

11–8c. Circuits—Audio input at + 10 dbm, applied to a balanced input transformer, feeds a type 6SJ7 audio amplifier. Amplifier output drives a type 1614 modulator control tube which in turn operates the frequency modulator. A simplified circuit employing only resistance, capacitance and two type 6H6 diode tubes constitutes the modulator, thus providing variation of the tank circuit frequency without additional tuned circuits. The use of diodes reduces microphonics to a minimum; and to effect noise reduction and insure high-fidelity, a discriminator-type feedback circuit with a type 6H6 tube is coupled between the master oscillator tank circuit and the type 6SJ7 audio amplifier.

The frequency control unit performs the function of providing frequency correction voltage to the F–M generator to maintain the carrier at the assigned frequency. And it is here that a revolutionary development in F–M control circuits has been utilized; nowhere does the development of the correcting voltage depend upon the stability of a tuned circuit.

The r-f reference voltage is developed in a temperature-controlled crystal oscillator (supplied in duplicate) that uses a type 1614 tube operating at 1/18 the assigned center frequency. This crystal is a Bliley type TC–91, BT-low-temperature-coefficient cut, 1 cycle/mc/degree C, constantly maintained at correct operating temperature.

The second harmonic of the crystal oscillator output is applied to two fixed phase-shift circuits to obtain two voltages at reference frequency at a fixed 90° phase relation. These signals are each mixed in two type 6SA7 tubes, with a portion of the F–M master oscillator output.

Thus, if the center frequency deviates from its assigned value, each mixer tube develops a beat-frequency voltage dependent upon the difference between the F–M oscillator frequency and the crystal oscillator frequency, and these two beats are out of phase by a fixed 90°.

These beat signals are applied to pulse-counting circuits to develop the frequency correcting voltage. The polarity of the correction voltage corresponds to the direction of deviation of the oscillator center frequency and is always of the proper sign to return the F–M oscillator to the crystal second-harmonic frequency.

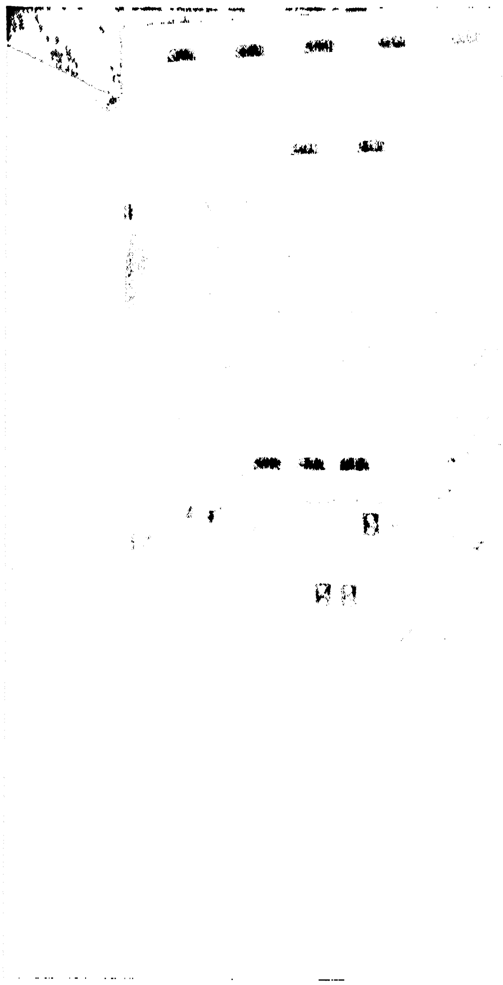


Fig. 11–4. G.E. BT-1-A 250-watt F-M radio broadcast transmitter.

The circuit maintains a close frequency control without the use of critically-tuned elements or moving parts which simplifies both construction and adjustment as well as improving reliability. A detailed description of the frequency control circuits will be found in Chapter 7.

The modulated master oscillator employs two type 1614 tubes operating in push-pull at ⅙ the assigned center frequency. The tank circuit frequency is tripled in the oscillator plate circuit and again tripled in the next stage, a type 815 tube, to provide output at the assigned frequency.

The next stage, a type 815 tube, amplifies the modulated carrier to a 12.5-watt output. This tube drives a type 4–125A tube that in turn drives the type WL–473A tube in a cathode-input grounded-grid, power amplifier circuit.

A vacuum-tube voltmeter in the transmission line output circuit indicates transmitter power output.

11–8d. Technical Data

	TYPE FM-1	TYPE FM-3
Power output	1000 watts	3000 watts
Frequenty range (single specified frequency)	88–108 mc/s	88–108 mc/s
Center-frequency stability	±1000 cycles	±1000 cycles
Modulation capability	±100 kc	±100 kc
Audio-frequency response, 50 to 15,000 cps	±1 db from 1000 cycle value without pre-emphasis; ±1 db from 75 microsecond curve with pre-emphasis	±1 db from 1000 cycle value without pre-emphasis; ±1 db from 75 microsecond curve with pre-emphasis
Audio-frequency harmonic distortion, ±75 kc swing	Not greater than	Not greater than
50–15,000 cps	1.5% rms	1.5% rms
100–7,500 cps	1.0% rms	1.0% rms
Frequency-modulation noise	At least 65 db below 75 kc swing	At least 65 db below 75 kc swing
Amplitude-modulation noise	At least 50 db below 100% amplitude modulation	At least 50 db below 100% amplitude modulation
Audio-input level for 100% modulation (75 kc swing)	+10 dbm±2 db	+10 dbm±2 db
Audio input impedance	600/150 ohms	600/150 ohms
R-f output coupling impedance range	40–80 ohms	40–80 ohms
Power supply	208/230 volts, single-phase, 50 or 60 cycles	208/230 volts, 3-phase, 50 or 60 cycles
Power input	3600 watts at 90% power factor	8500 watts at 90% power factor

11–8e. Tube Complement

TYPE FM-1 TRANSMITTER	*Quantity*
Type 6SJ7 (audio amplifier)	1
Type 1614 (modulator control)	1
Type 1614 (FM master oscillator)	2
Type 6H6 (feedback discriminator)	1
Type 6H6 (resistance modulator)	2
Type 815 (r-f tripler)	1
Type 815 (intermediate amp.)	1
Type 4-125A (r-f driver)	1
Type WL-473A (power amplifier)	1
Type 6SA7 (freq. control buffer)	1
Type 6SA7 (freq. control mixer)	2
Type 1614 (crystal oscillator)	2
Type 6SN7 (pulse generator)	2
Type 6H6 (pulse detector, limiter and charging rectifiers)	4
Type 6SL7 (pulse, bias and output amplifier)	2
Type 6X5 (bias rectifier)	1
Type WL-872A (h.v. rectifier)	2
Type WL-866A (l.v. rectifier)	2
Type 6Y6G (voltage regulator)	2
Type 6SJ7 (voltage regulator)	1
Type OC3/VR105 (voltage regulator)	2
Type OD3/VR150 (voltage regulator)	2
Type 9006 (v.t.-voltmeter)	1

TYPE FM-3 TRANSMITTER. In the 3-kw apparatus, the r-f driver has two type 4–125A tubes, and the power amplifier uses two type WL–473A tubes and the h.v. rectifier uses six type WL–872A tubes.

11–9. General Electric F–M Broadcast Transmitters—Following is a description of the General Electric BT series of F–M broadcast transmitters. The power output ratings in watts of these transmitters are:

BT-1-A	250
BT-2-A	1000
BT-3-A	3000

The BT–1–A equipment is the basic unit around which higher power transmitters can be built. The air-cooled, Z-7C29 tubes are used in the power amplifier stage of the BT–2–A transmitter, while the Z–7D21 screen grid tubes are used in the BT–3–A transmitter.

11–9a. Electrical Design—Frequency control and modulation are independently accomplished electronically through the use of the "Phasitron" tube. A single crystal directly controls the output carrier frequency. The modulation process in the Phasitron tube is "phase modulation," but the characteristics of the field producing the modulation are such that the output is "frequency modulation." The temperature-controlled crystal oscillator output is modulated directly by the Phasitron tube, multiplied to the output carrier frequency, and amplified to the required power level. An explanation of the operation of the Phasitron will be found in Chapter 7.

Block diagrams of the BT–1–A and BT–2–A transmitters are shown in Figures 11–5 and 11–6 respectively. A block diagram of the BT–3–A transmitter would be similar to that of the BT–2–A except that the power amplifier stage would have a 3000-watt output rating.

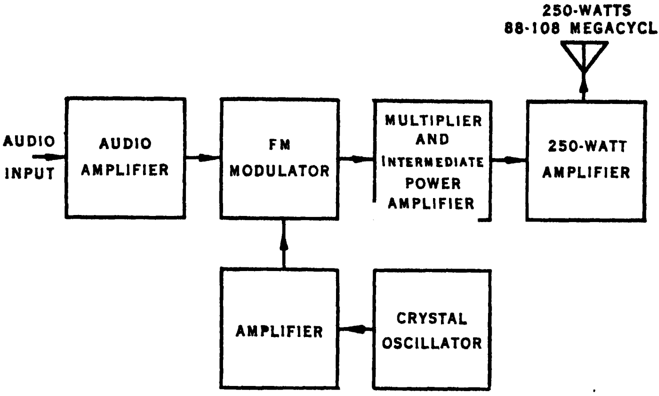


Fig. 11–5. Block diagram of 250-watt F-M broadcast transmitter, General Electric BT-1-A.

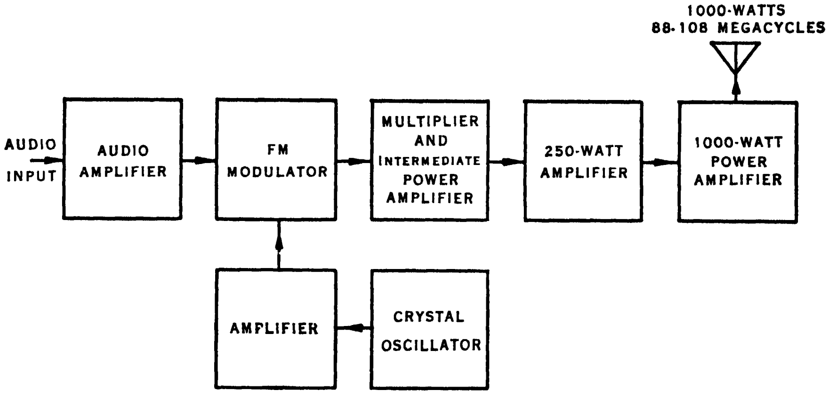


Fig. 11–6. Block diagram of 1000-watt F-M broadcast transmitter, General Electric BT-2-A.

11–9b. Performance Characteristics—The performance characteristics of the BT–1–A transmitter are:

1. *Carrier power output:* 250 watts.
2. *Carrier frequency range:* 88 to 108 mc.
3. *Carrier frequency stability:* Within 1000 cps. over normal room temperature range.
4. *F–M carrier-noise level:* 65 db below ± 75 kc swing, unweighted.
5. *A–M carrier noise level:* 50 db below 100% amplitude modulation, unweighted.
6. *R-f load characteristics:* The r-f output coupling circuit is designed to operate into an unbalanced load impedance having a resistive component in the range 40 to 80 ohms and a power factor not less than 0.866. Provisions are made for the use of a single ⅞-inch coaxial transmission line having a surge impedance of 50 ohms.
7. *Modulation capability:* ± 100 kc carrier swing, 50 to 15,000 cps with less than 3% rms distortion.
8. *Audio input level:* + 12 dbm ± 2 db required for 100% modulation at 400 cps; input impedance, 600 ohms.
9. *Audio response:* Within ± 1 db of F.C.C. pre-emphasis standard from 50 to 15,000 cps.
10. *Audio harmonic distortion:* Less than 1.5% rms for any single modulating frequency from 50 to 15,000 cps and less than 1% rms from 100 to 7500 cps at a carrier swing up to ± 75 kc.
11. *Intermodulation distortion:* Less than 1.5% rss distortion at a carrier swing of ± 75 kc with combinations of 400 and 700 cps and 4000 and 7000 cps.
12. *Power supply:* 208/230 volts, 50/60 cps single-phase. A continuously variable input voltage control makes it possible to operate with any supply voltage in the range 195–245 volts. In addition, a small amount of power is required from the station lighting supply at 115 volts for the crystal thermocell heater.
13. *Power input:* Approximately 1.3 kw at 90% power factor.

The performance characteristics of the higher powered BT–2–A and BT–3–A transmitters differ only in the rated power output and the primary power supply requirements.

11–9c. Features—The modulation characteristics of the Phasitron tube are such that these transmitters operate with improved noise level, distortion, and frequency response. Other electrical features are:

1. No neutralization. High-frequency screen-grid tubes are used in the power amplifier stages.
2. Conservative operation of all tubes for long life and reliability.
3. High-efficiency power amplifier output circuit.
4. Metering of all important circuits.
5. Door-operated, high-voltage interlock and grounding switch for safety.
6. Continuously variable input voltage control. This control makes it possible to operate the transmitter from a power supply voltage in the range 195–245 volts.
7. Fast-acting a-c and d-c overload protection.
8. Time-delay protection of rectifier filaments.
9. Design co-ordinated with high-power amplifier units to make possible power increases without changes in existing equipment.
10. Simplified control circuit, isolated from main power source and grounded for safety.

11–9d. Tube Complement—The tube complement of the General Electric BT–1–A, BT–2–A, and BT–3–A transmitters follows:

BT-1-A	*Type*	*Number*
Audio amplifier	6SL7	1
	6SN7	1
Crystal oscillator	6SJ7	1
Crystal amplifier	6SJ7	1
Phasitron	GL-2H21	1
Frequency multipliers	6SJ7	5
	6V6	1
	GL-815	1
Intermediate power amplifier	GL-829-B	1
Power amplifier	Eimac 4-250A	2
Transmission line voltmeter	6H6	1
Power supplies and voltage regulator	GL-866-A/866	2
	5R4-GY	2

BT-2-A	*Type*	*Number*
Audio amplifier	6SL7	1
	6SN7	1
Crystal oscillator	6SJ7	1
Crystal amplifier	6SJ7	1
Phasitron	GL-2H21	1
Frequency Multipliers	6SJ7	5
	6V6	1
	GL-815	1
Buffer amplifier	GL-829-B	1
Intermediate power amplifier	Eimac 4-250A	2
Power amplifier	Z-7C29	2
Transmission line voltmeter	6H6	1
Power supplies and voltage regulator	GL-8008	2
	GL-866-A/866	2
	5R4-GY	2
	6B4-G	3
	6SJ7	1
	OC3/VR105	1

BT-3-A	*Type*	*Number*
Audio amplifier	6SL7	1
	6SN7	1
Crystal oscillator	6SJ7	1
Crystal amplifier	6SJ7	1
Phasitron	GL-2H21	1
Frequency multipliers	6SJ7	5
	6V6	1
	GL-815	1
Buffer amplifier	GL-829-B	1
Intermediate power amplifier	Eimac 4-250A	2
Power amplifier	Z-7D21	2
Transmission line voltmeter	6H6	1
Power supplies and voltage regulator	GL-8008	6
	GL-866-A/866	4
	5R4-GY	2
	6B4-G	3
	6SJ7	1
	OC3/VR105	1

11–10. REL 10,000–Watt Model 520 DL Quadriline F–M Broadcast Transmitter—Radio Engineering Laboratories 10,000-watt model 520 DL quadriline F–M broadcast transmitter is designed for operation on any selected frequency between 88 and 108 mc. The electrical performance is better than F.C.C. requirements for F–M broadcast service and better than R.M.A. standards applicable to F–M broadcast transmitters. All components are moisture-proofed and in every way conform to the most rigid specifications. Inductors, busses, and other parts in the high-frequency circuits are heavily silver-plated. The unit is designed to operate satisfactorily over a temperature range from 0° C to + 60° C.

One of the outstanding features incorporated in the transmitter design is an automatic recycling device which functions in such a manner that with overload it will reduce the power amplifier high voltage to a lower value. Should the overload reoccur, the high voltage is again reduced, with this cycle continuing until the overload clears or the voltage is reduced to zero. High voltage can be restored or returned to its former value at the discretion of the operator by means of push switches located on the equipment front panel or desk control unit. Voltage is reduced in discrete steps and pilot lights at all times indicate the value of high voltage in use.

11–10a. Construction—The complete transmitter consists of three basic units which may be assembled in a variety of ways to suit available building space. The basic units are:

1. The 1-kw model 518 DL transmitter driver unit is housed in a cabinet 84 inches high by 40 inches wide by 36 inches deep. This cabinet contains the Armstrong crystal-controlled phase shift modulator, one-kilowatt power amplifier, and associated power supplies. Each chassis in the modulator section is mounted on hinges allowing them to be swung separately into a position of accessibility for all components. Modulator high voltage, bias supply, and control circuits are likewise

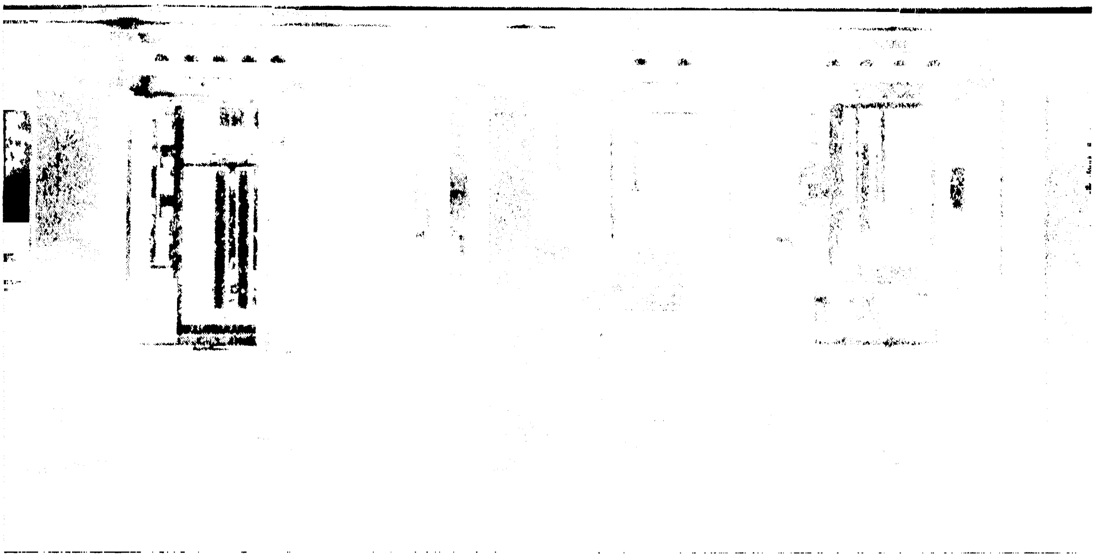


FIG. 11–7. Front view of the 10-kw quadriline F-M transmitter developed by Radio Engineering Laboratories. From left to right (a) the 1-kw model 518 DL driver unit which includes the dual channel modulator, (b) access doors to rear of transmitter units, (c) the 10-kw amplifier power supply and control circuits, (d) the 10-kw quadriline power amplifier.

mounted on hinged panels. Access to the modulator proper is through two hinged doors located at the rear of the cabinet.

2. The 10-kw power supply and control circuits are housed in a cabinet of the same dimensions as the driver. It contains the power amplifier high-voltage power supply with motor-driven primary tap switch, control relays, and switches and bias and screen voltage power supplies for the power amplifier tubes. An automatic high-voltage filter condenser shorting device is provided which operates from the door interlock circuits.

3. The 10-kw power amplifier is similarly housed in a cabinet of the same dimensions as that of the driver and contains the four power amplifier tubes, and associated grid and plate lines, connected in the quadriline circuit, as well as one filament transformer with variac control, and one blower for each pair of tubes. Driver output power is coupled to the P.A. grid circuit via a ⅞-inch co-axial line running over the top of the cabinets, while output power to the antenna is fed via either two 1⅝-inch co-axial, one 3⅛-inch co-axial, or open-wire transmission line. Individual screen current meters for each of the four final amplifier tubes are provided together with individual screen voltage controls which simplify final balance adjustment.

The cabinet fittings are of rugged construction and include specially designed door grips and concealed hinges. The doors and removable panels are fitted with switches that are connected into the safety inter-lock system. Cabinet doors are fitted with additional switches which turn on interior lights to facilitate servicing. Each cabinet is pressurized and openings are sealed with special gaskets. Air intakes in the individual cabinets are provided with filters that will last indefinitely.

It is recommended that power lines to the equipment be brought up through floor trenches. The cabinets are so designed that power may be brought in from the bottom, thus entirely concealing the lines. However, provision is made for exposed conduit wiring if desired, by means of conduit knock-outs. Convenience a-c outlets are mounted in the rear of each unit.

Each cabinet is provided with large-scale illuminated meters from which voltage and other conditions in the high power circuits can be read. The principal circuits in the modulator chassis are equipped with built-in meters and all other important circuits may be examined through tip jacks. The front panel of the P.A. cabinet carries a meter which is connected to a vacuum tube voltmeter arranged to measure r-f voltages on the output transmission line. This meter is a means of monitoring relative power outputs and is approximately linear with power.

11–10b. Technical Data

Operating frequency: Any single frequency in the 88 to 108 mc band.

Power output: 3000 to 10,000 watts, as measured into a properly terminated transmission line. Power output coupling is designed to permit the use of any type transmission line.

Primary power: 208/230 volts, 60 cycles, 3 phase, 19,300 volt-amperes for 10,000 watts output, providing an over-all efficiency from a-c line to antenna of approximately 53%.

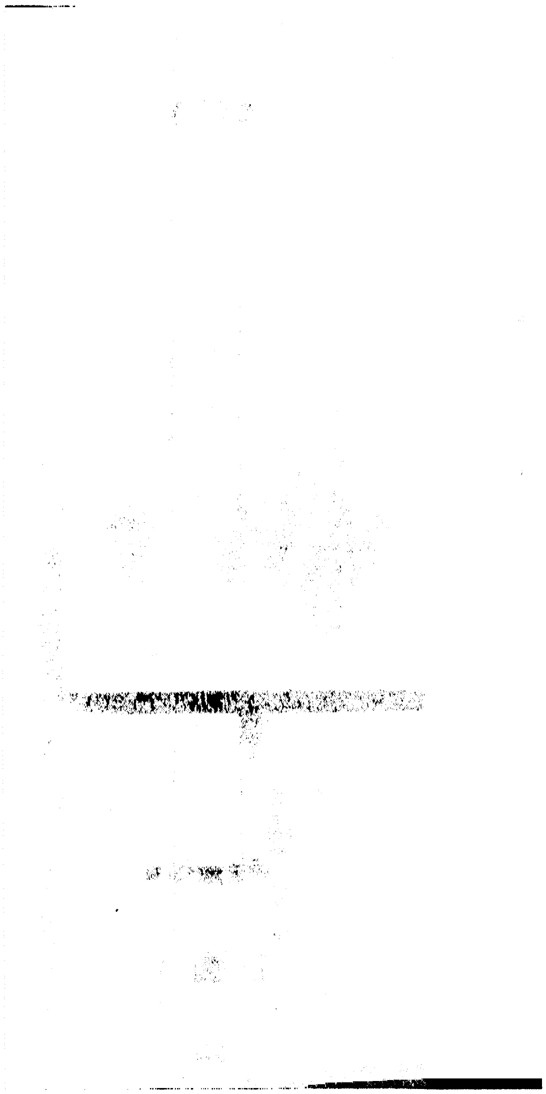


FIG. 11–7a. A close-up of the output stage of the REL 518 DL 1-kw driver. Two Eimac 4X500A tetrodes are used This unit may be employed as a complete 1-kw transmitter.

Audio input · Audio input level for 100% modulation is + 12, ± 2 dbm. Input impedance, 600 ohms balanced to ground.

Monitor output: 2 watts r.f. at operating frequency for frequency-modulation monitor.

Frequency stability: ± 2000 cycles.

Fidelity: Over-all response is within ± 1 db from 50 to 15,000 cycles at 25%, 50%, and 100% modulation.

Distortion: The measured rms harmonic distortion is less than 1½% for all signal frequencies between 50 and 15,000 cycles at 25%, 50% and 100% modulation.

Noise level: F–M signal-to-noise ratio is at least 70 db below 100% modulation measured at the output of a monitor receiver within a band of 50 to 15,000 cycles. A–M signal-to-noise ratio is at least 55 db below 100% modulation measured at the output of a monitor receiver within a band of 50 to 15,000 cycles.

Maximum swing: ± 100 kc.

11–10c. Tube Complement

Model 518 DL 1-Kw Driver

Two 4X500A
Four 872A
Two 5U4G
Two 3B25
Four 6B4G
One VR–105
One 7F8
Two 7N7
Three 7O7
Three 7A7
Fifteen 7C7
Two 7C5
Two 829B
One 2X2

Model 520 DL 10-Kw Power Supply

Two 3B25
Two 5R4GY
Seven 872A (one on standby)

Model 520 DL Quadriline 10-Kw Power Amplifier

Four 4–1000A

FIG. 11–7b. A close-up of the 10-kw REL quadriline amplifier. This amplifier employs 4 Eimac 4-1000A tetrodes, the resonant input and output circuits consisting of short sections of four-wire line.

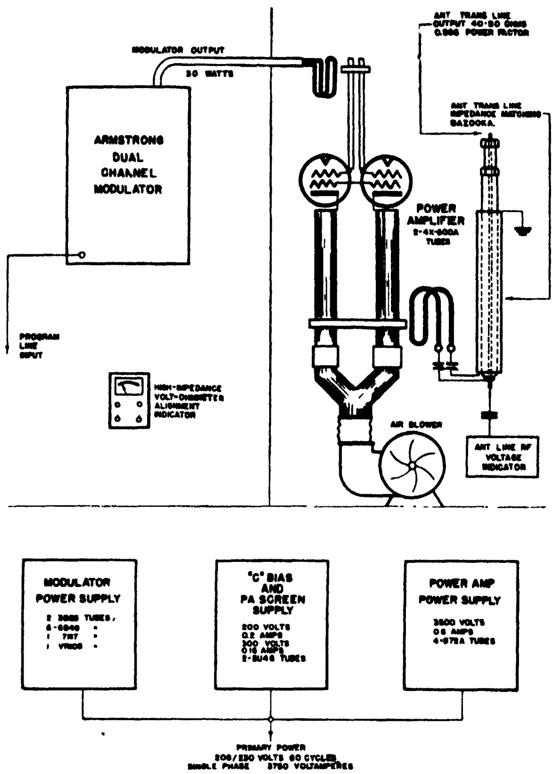

ANT TRANS LINE OUTPUT 40-80 OHMS 0.966 POWER FACTOR
MODULATOR OUTPUT
30 WATTS
ARMSTRONG DUAL CHANNEL MODULATOR
ANT TRANS LINE IMPEDANCE MATCHING BAZOOKA
POWER AMPLIFIER 2-4X-500A TUBES
PROGRAM LINE INPUT
HIGH-IMPEDANCE VOLT-OHMMETER ALIGNMENT INDICATOR
AIR BLOWER
ANT LINE RF VOLTAGE INDICATOR
MODULATOR POWER SUPPLY
2 3888 TUBES,
6-6846 "
1 7N7 "
1 VR105 "
"C" BIAS AND PA SCREEN SUPPLY
200 VOLTS
0.2 AMPS
300 VOLTS
0.15 AMPS
2-5U4G TUBES
POWER AMP POWER SUPPLY
3500 VOLTS
0.6 AMPS
4-872A TUBES
PRIMARY POWER
208/230 VOLTS 60 CYCLES
SINGLE PHASE 3750 VOLTAMPERES

Fig. 11–8. Simplified diagram of the REL 518 DL 1-kw driver unit.

11-11. Federal F-M Radio Broadcast Equipment—In Federal's "Frequematic" F-M modulator, frequency modulation rather than phase modulation is employed, and a much higher initial frequency of approximately 4 mc is used, thereby eliminating to a large extent the difficulty encountered by excessive multiplication of minor modulations produced by power supply ripple or microphonics. The modulating capabilities of the FTR frequency modulator are such that a frequency excursion many times that set up by the F.C.C. as representing 100-percent modulation can be obtained with very low distortion.

Five pentode stages, three of them being doublers, one a tripler, and one a buffer-amplifier, follow the modulated oscillator in the equipments. Two push-pull pentode stages, at the final output frequency, increase the power to 2500 watts, followed by a pair of push-pull triodes to either 1000 watts or 3000 watts. The 1-kw power amplifier is identical to the 3-kw power amplifier, except that the former uses a plate voltage of 2000 volts, while the latter uses 3000 volts.

In line with R.M.A. recommendations, the primary power of the 1-kw transmitter is obtained from a single-phase, 220-volt power source, while the 3-kw unit operating at higher power, requires a three-phase, 220-volt source.

11-11a. Power Tubes—Power tubes developed by Federal are employed in the power amplifier stages of all F-M transmitters. These air-cooled,

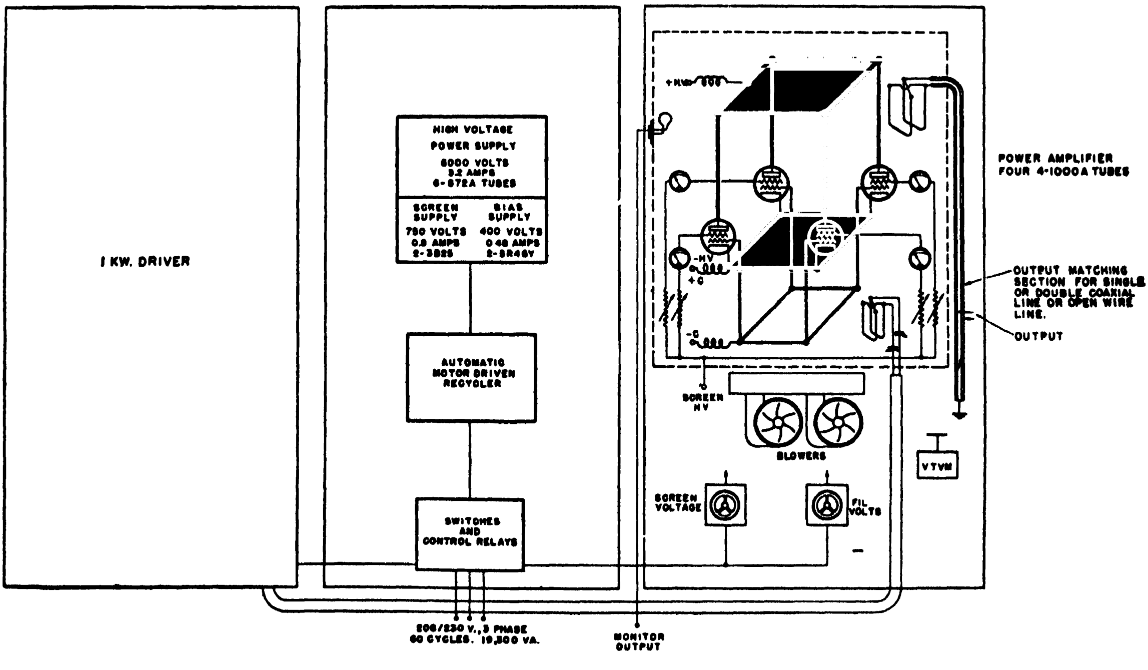

1 KW. DRIVER
HIGH VOLTAGE POWER SUPPLY
6000 VOLTS
3.2 AMPS
6-872A TUBES
SCREEN SUPPLY
750 VOLTS
0.8 AMPS
2-3B25
BIAS SUPPLY
400 VOLTS
0.48 AMPS
2-5R4GY
AUTOMATIC MOTOR DRIVEN RECYCLER
SWITCHES AND CONTROL RELAYS
208/230 V., 3 PHASE 60 CYCLES. 19,300 VA.
MONITOR OUTPUT
+HV
-HV
+C
-C
SCREEN HV
BLOWERS
SCREEN VOLTAGE
FIL VOLTS
VTVM
POWER AMPLIFIER FOUR 4-1000A TUBES
OUTPUT MATCHING SECTION FOR SINGLE OR DOUBLE COAXIAL LINE OR OPEN WIRE LINE.
OUTPUT

Fig. 11–9. General arrangement of the REL model 520 DL 10,000-watt F-M broadcast transmitter.

high-efficiency vacuum tubes assure long life, stable operation at 100 mc, and low noise level. Typical of the improved power tube developed by Federal is the FTR 7C26 triode, the characteristics of which are given below. Two of these tubes are used in the Federal 1-kw and 3-kw F–M transmitters in grounded filament circuits.

DATA ON 7C26

Filament type	Thoriated tungsten
Filament voltage	9.0 volts
Filament current	28.5 amp
Available peak emission	8.5 amp
Amplification factor	17
Mutual conductance	20,000 μumhos
Type of cooling	Forced-Air 75 CFM
Maximum over-all dimension	
Length	4¼ inches
Diameter	2½ inches
Approximate direct interelectrode capacitances	
Plate to grid	12 μμf
Grid to filament	12 μμf
Plate to filament	1.0 μμf

Maximum Ratings and Typical Operation for Maximum Frequency of 150 Mc

Class C power amplifier and oscillator	
Key-down conditions without amplitude modulation	
Maximum ratings	
D-c plate voltage	3000 volts
D-c plate current	1.0 amp
Plate input	3000 watts
Plate dissipation	1000 watts
D-c grid current	0.1 amp.
D-c grid voltage	−800 volts
Typical operation	
D-c plate voltage	3000 volts
D-c plate current	1.0 amp.
Power output	2350 watts
Plate efficiency	79%
Class C high level amplitude-modulated amplifier for use with a maximum modulation factor of 1.0 maximum ratings	
D-c plate voltage	2500 volts
D-c plate current	.815 amp
Plate input	2000 watts
Plate dissipation	660 watts
D-c grid current	1.0 amp
D-c grid voltage	−800 volts
Typical operation	
D-c plate voltage	2500 volts
D-c plate current	0.815 amp.
Power output	1580 watts
Plate efficiency	78%

11–11b. Mechanical Characteristics—In the mechanical design of the FTR F–M radio transmitter, simplicity of control has been emphasized, together with arrangements for complete accessibility of component parts. Electrical components are so assembled on vertically mounted aluminum chassis that they are entirely accessible from both front and rear. Appreciating the necessity for quick removal and replacement of components, these transmitters were designed with this feature in mind. It is possible to service any one of the components without interfering with others.

The operating controls are arranged on vertical front panels, one on the right and one on the left. Switches and controls are an integral part of the main chassis, and the individual controls are mechanically adjusted at the factory.

1. *Cabinet.* The FTR F–M broadcast equipment is housed in a cabinet of modern design which presents a highly attractive appearance and enables convenient access to all components as well as insuring protection to the operator. The cabinet is finished in a beige color which very successfully blends with the remainder of the equipment.

Complete access to all apparatus locked in the rear side of the vertical chassis is possible through the full length doors located in the rear. Complete personnel protective circuits are used in conjunction with these doors which are electrically integrated with the control circuits so that all power is cut off when the door is open. Included in this protective system is a switch which automatically shorts out the rectifier bus when the door is opened.

Two full-length front doors cover the operating front of the transmitter proper. These doors are opened by a centrally located knob which operates a three-point catch. Upon opening the front doors, the operating front of the transmitter is exposed. Accessibility into the fronts of the vertical chassis is accomplished by opening small access doors which cover the various units in the transmitter. Each door giving access to high voltage is interlocked with the high-voltage power supplies to insure operating personnel safety. The cabinet is constructed entirely of aluminum to minimize weight and to minimize corrosion.

2. *Weight.* The 1-kw unit weighs approximately 1500 pounds, the 3-kw unit approximately 2000 pounds, and the 250-watt unit approximately 750 pounds.

3. *Dimensions.* 1-kw and 3-kw units: 66½ inches wide, 39½ inches deep, 83 inches high; 250-watt unit: 34¼ inches wide, 39½ inches deep, 83 inches high.

4. *Ventilating and Air Filtering.* One blower provides forced air cooling for the 250-watt transmitter while two blowers are used for the 1-kw and 3-kw transmitters. These are mounted on rubber-cushioned mounting cradles. Filters in the rear of the transmitter prevent entrance of dust when the blowers are in operation, and the air outlet at the top of the cabinet is covered by copper screening to prevent the entry of foreign substances.

Warning of excess temperature, such as might be caused by failure of the blower or by clogging of the air-intake filter, is given by thermostat, buzzer, and an indicating light on the front panel.

The exciter unit is cooled by means of a duct system running up the left side of the equipment. The duct is provided with openings which discharge air horizontally, allowing complete cooling of components. The air then flows upward through the vertical chassis, due to chimney effect, thereby providing the most efficient type of cooling possible.

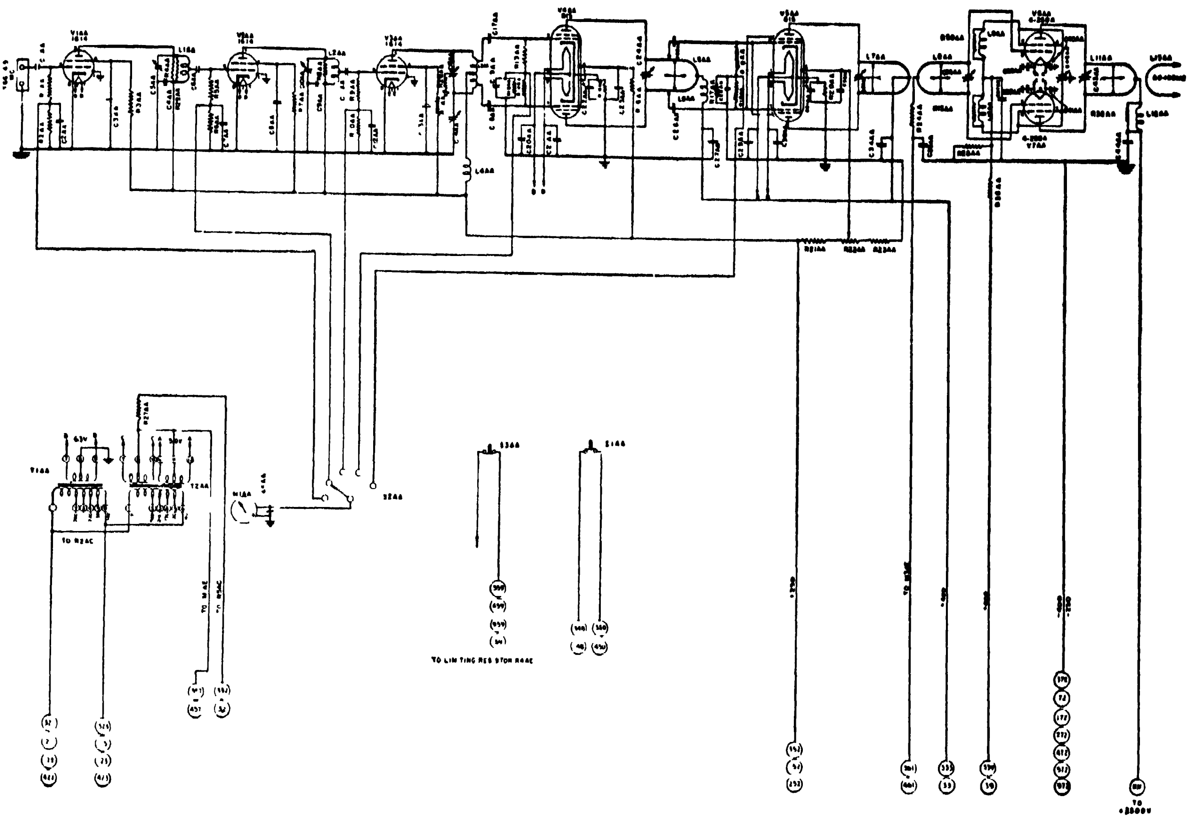


Fig. 11–10. Federal 250-watt F-M exciter unit.

The cooling in the power amplifier unit is accomplished by duct work which channels air directly to the radiator elements of the air-cooled tubes.

5. *Arrangement of Component Units.* The F-M transmitter consists of two individual sections made integral by means of unified cabinet design. The left section, known as the "exciter unit" consists of a meter panel, intermediate power amplifier, multiplier, a modulator, a regulated power supply, and a control unit.

The right section consists of a meter panel, a power amplifier, and a power supply and control unit.

11–11c. Technical Data

1. *Frequency range:* 88 to 108 mc.

2. *Modulation:* Linear modulation of all audio signals between 50 and 15,000 cps is maintained even when the transmitter is overmodulated by as much as 300%. The modulator circuits are independent of the center-frequency control system and will operate correctly even if the CFS unit is removed.

3. *Audio input level:* Program level approximately 0 vu for full modulation of ± 75 kc per second. Single-frequency level of + 10 dbm for same excursion.

4. *Frequency response:* Flat for all audio signals between 50 and 15,000 cps to within ± 1 db.

5. *Noise level:* The F-M noise present in the transmitted wave measured under normal broadcast conditions is – 65 db below full carrier modulation.

6. *Pre-emphasis of audio frequencies:* Pre-emphasis circuits, in accordance with R.M.A. standards, have been provided at the audio input. The use of this circuit is optional and can be cut out if so desired.

7. *Frequency stability:* The mean frequency of the master oscillator is synchronized to that of a temperature-controlled quartz crystal, thus maintaining the center frequency to within 0.001% of its assigned value.

8. *Primary power:* 250-watt exciter operates from a 220-volt, single-phase, 60-cps power source, and requires an input of 3¾ kva for full power output.

1-kw transmitter operates from a 220-volt, single-phase, 60-cps power source, and requires an input of 5½ kva for full power output.

3-kw transmitter operates from a 220-volt, three-phase 60-cps power source, and requires an input of 8½ kva for full power output.

9. *Control system:* Toggle and push button switches control the application of power to the transmitter. For normal on-off control, a single

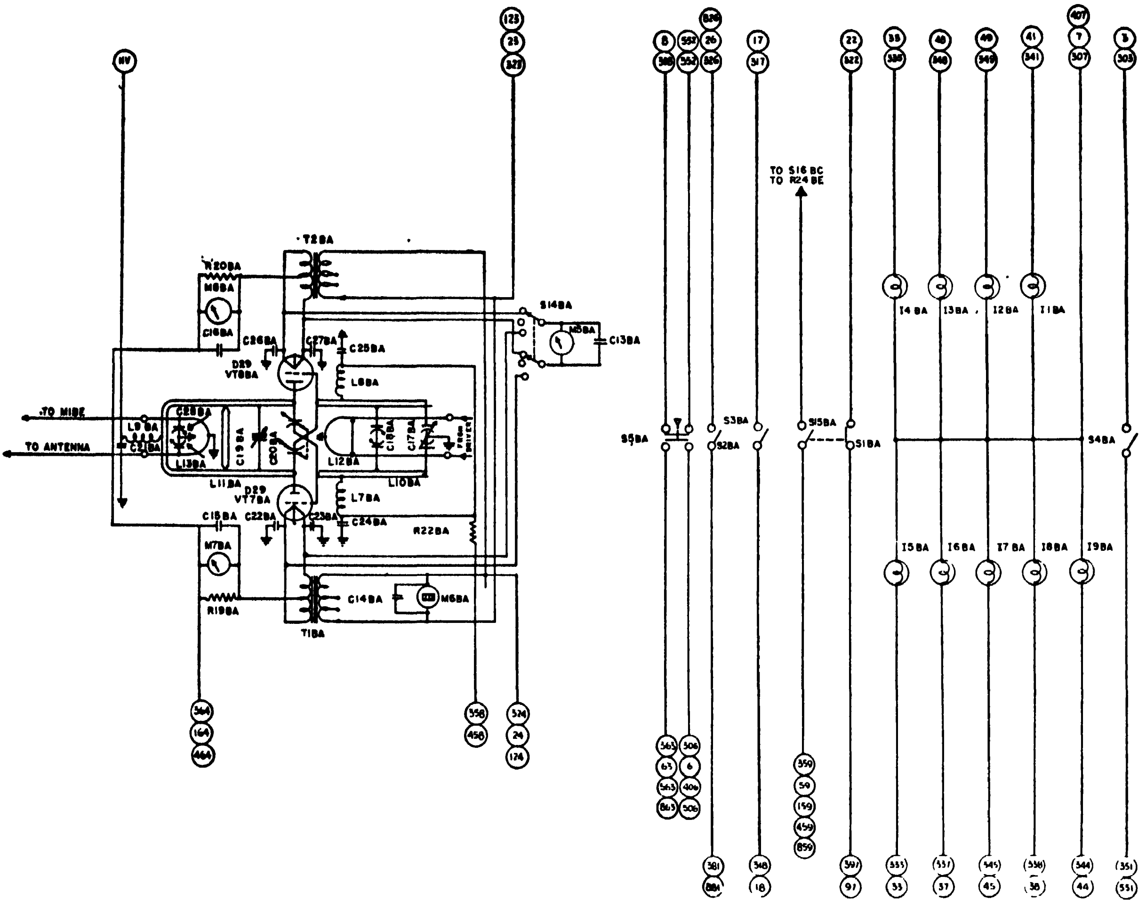


FIG. 11-11. R-f unit of Federal 1-kw F-M transmitter.

master switch is used with the sequencing and time delay cycling entirely automatic. Individual plate and bias switches are provided for maintenance and checking purposes. Automatic time delay equipment for filament preheating is a standard feature of this unit.

11-11d. Technical Description of "Frequematic" Modulator—The solution of one of the major problems in F-M transmitters, stability of the mean frequency, as well as an improved method of direct frequency modulation, has been accomplished by the Federal Telephone and Radio Corporation. Utilizing an all electronic system, permitting performance well within limits established by the F.C.C. "Standards of Good Engineering Practice," this unit features simplicity and economy, for it employs standard receiver tubes and contains only two tuned circuits.

The mean carrier frequency is precisely controlled by means of a crystal via a method of frequency division. The frequency division is accomplished through multivibrator circuits which depend mainly on resistance and capacitance components for critical and non-critical functions, thus enabling the equipment to have outstandingly stable and rugged mechanical as well as electrical characteristics. In addition, it assures extreme ease of initial alignment and a minimum of operational maintenance.

Some essential features of the Federal F-M center-frequency-stabilization modulator system are:

1. *Operational Features*
   (a) Precision lock-in of carrier to crystal frequency by frequency division and phase comparison.
   (b) High performance with simple single-ended modulator circuits:

A-F Distortion.........	0.5%
F-M Noise............	75 db below 100% modulation
A-M Noise............	60 db below carrier level

   (c) All-electronic action.
   (d) Correct modulator emergency operation with center frequency control system inoperative.
   (e) Wide-range frequency pull-in (± 50 kc).

2. *Circuit Features*
   (a) No tuned circuits in crystal oscillator.
   (b) Minimum number tuned circuits (only two).

(c) Untuned-type frequency dividers.
(d) D-c operation of filaments.
(e) Carrier deviation indicating meter.
(f) Single crystal used with spare crystal provision.
(g) Maximum accessibility to tubes and all circuit components for check or replacement.
(h) Standard tubes throughout.

The Federal modulator unit, the circuit of which is shown in Figure 11–15, is of extremely simple design using only three tubes, a 12J5 oscillator, a 6AB7 modulator, and a 6AB7 buffer. Modulation is effected by reflection of the effective capacitive variation of the modulator tube grid circuit across the master oscillator tank. This capacitive change is proportional to the total voltage on the 6AB7 modulator tube grid which is the sum of the program audio frequency input and the CFS phase detector output voltages. Thus the modulator not only converts the audio voltage into the desired frequency variations, but also acts in conjunction with the CFS system to maintain accurately the mean carrier frequency in exact coincidence with that of the temperature-controlled precision crystal.

The linear relationship between the input capacitance and the transconductance of a vacuum tube amplifier is made use of in the Federal modulator to swing the frequency of a Hartley oscillator. Operating the modulator in its region of linear transconductance and applying a modulating signal to its control grid, we obtain an input capacitance, applied to the oscillator, directly proportional to the amplitude of the modulating signal (Figure 11–16).

To a first approximation, and for a qualitative discussion of the mechanism of the action of the modulator, it can be shown that the input capacitance of the vacuum tube is given by:

$$C_{in} = C_{gp}(1 + g_m R_L)$$

where R_L is the load impedance at resonance. Since the frequency of oscillator is approximately

$$\omega_0 = \frac{1}{\sqrt{LC}}$$

we have the differential of frequency, for an increment of capacitance ΔC:

$$d\omega = \left(\frac{d\omega}{dc}\right)\Delta C = \frac{-1}{2\sqrt{LC^3}}\Delta C = -\frac{\omega_0}{2C}\Delta C$$

This shows that the frequency swing is directly proportional to the change in injected capacitance and inversely proportional to the fixed tank capacitance C. To obtain a fixed frequency swing for a given

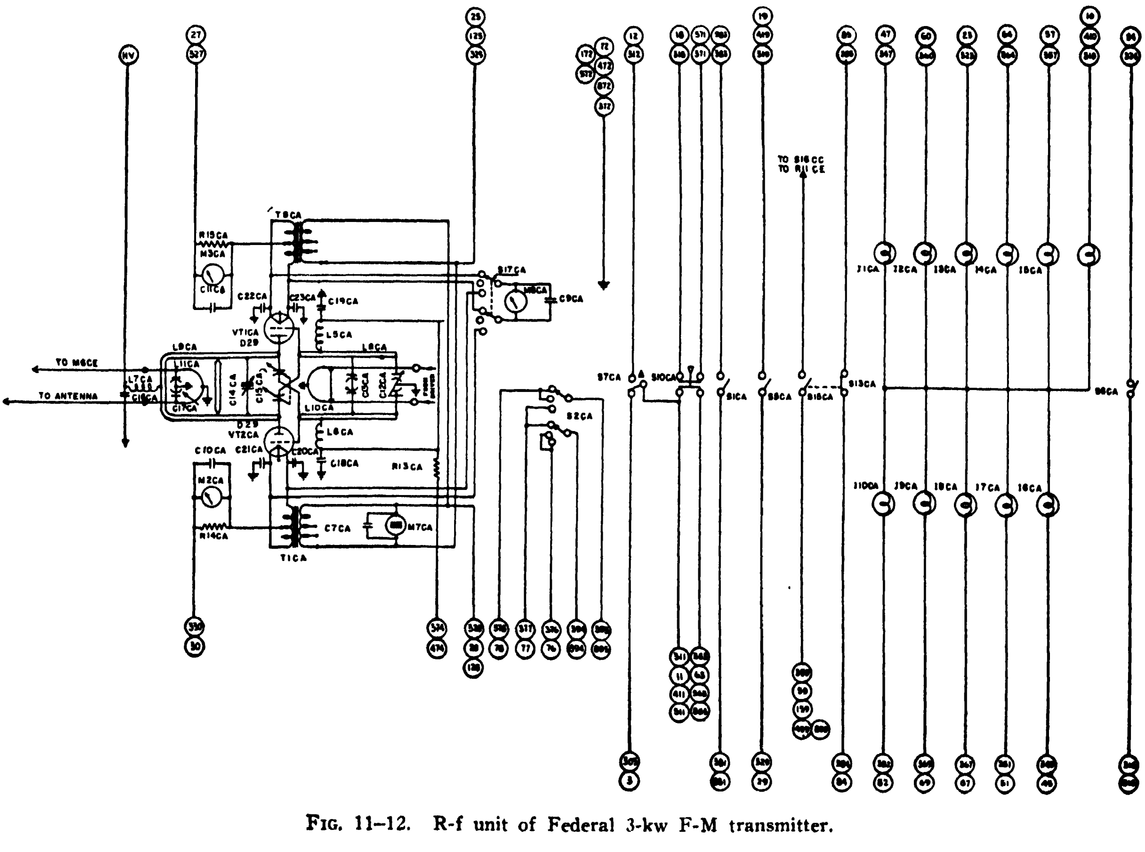


FIG. 11–12. R-f unit of Federal 3-kw F-M transmitter.

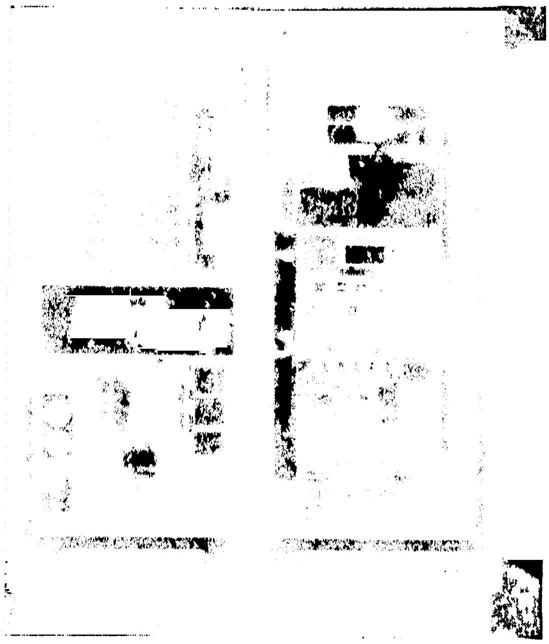


Fig. 11–13. Rear view of the FTR 1-kw F-M transmitter manufactured by Federal Telephone and Radio Corporation.

change in input capacitance, as the oscillator capacitance is changed to cover the frequency band, an adjustable capacitance C_c is used to couple the modulator to the oscillator. To reduce the r-f signal on the modulator grid, the capacitance is injected across only a portion of the tank inductance.

The Federal center-frequency stabilization system, Figure 11–17, is based upon the automatic synchronization of two oscillators, a crystal oscillator and a master frequency-modulated oscillator, to obtain mean center-frequency control. The frequencies of the crystal oscillator and the master oscillator are each divided to a common frequency and are then combined in a balanced phase detector. The integrated rectified output is used to actuate the Federal modulator so as to pull-in and lock the master oscillator mean frequency to that of the crystal oscillator.

If synchronization of the two frequencies is assumed, the output of the balanced phase detector depends on their relative phase. Any attempt of the mean frequency of the master oscillator to drift from the crystal frequency results in an instantaneous change of the phase difference of the two oscillations and a corresponding change in the rectified output of the phase detector, thereby acting on the Federal modulator to increase or decrease the master oscillator frequency and so restore synchronization.

If synchronization of the two frequencies is not assumed, the output of the detector is the beat difference between the divided crystal oscillation and the divided master frequency-modulated oscillation. This beat frequency, acting on the Federal modulator swings the carrier frequency of the master oscillator at a rate equal to the beat frequency and with a deviation proportional to the amplitude of the beat. If the deviation is made sufficiently large and the beat rate sufficiently low, the instantaneous frequency of the modulated oscillator is in near-synchronization with the crystal oscillation for a sufficient number of oscillation cycles for the condition of synchronization to take hold. Thereafter we have the condition described in the previous paragraph.

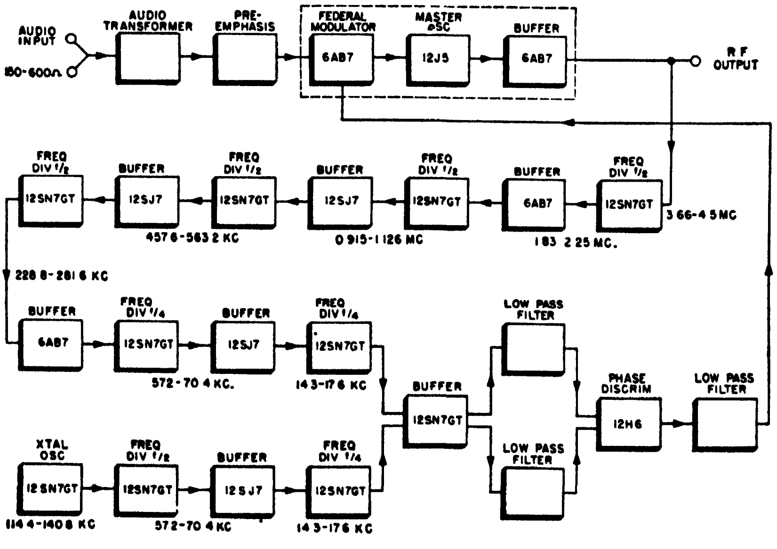


Fig. 11–14. Block diagram of Federal F-M center-frequency stabilization and modulator unit.

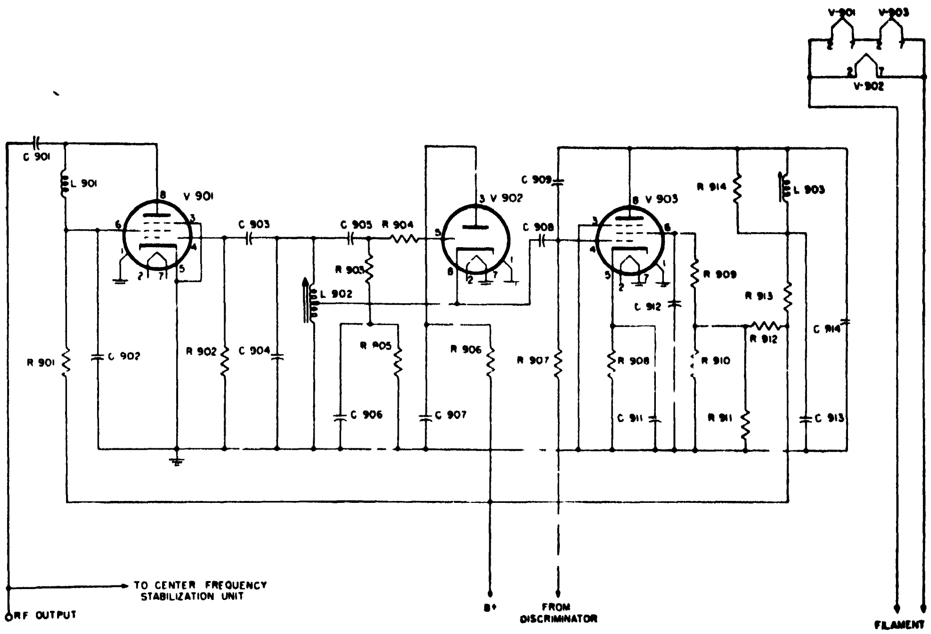


Fig. 11–15 Federal's "frequematic" F-M modulator.

It would not be possible to synchronize a frequency-modulated oscillator accurately with a crystal oscillator at the carrier frequency, since under modulation the carrier frequency amplitude is reduced and passes through innumerable conditions of zero amplitude. But if frequency division is performed, the effect is to reduce the frequency swing and the modulation index to an extent where the reduction of carrier amplitude is very small. In the present case, we have a maximum swing of 3 kc at an oscillator center frequency of 4 mc. A frequency division of 256 brings the maximum swing to 3000/256 = 12 cycles. Considering an audio frequency of 30 cycles, the maximum modulation index is 12/30 = 0.4 radians = 24°. This index reduces the carrier to 0.96 of its unmodulated value, giving an essentially constant carrier for synchronization. The crystal oscillator is also divided to a frequency corresponding to the divided frequency of the master oscillator.

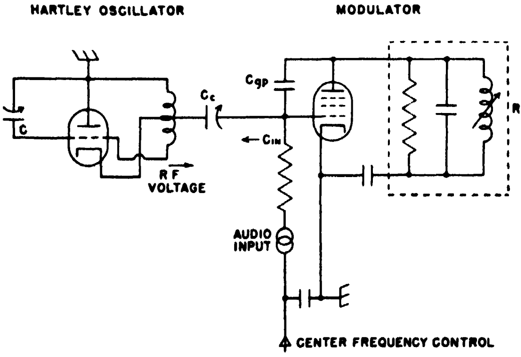


Fig. 11–16. Basic circuit of Federal modulator.

The dependence of control on a balanced phase detector, Figure 11–18, imposes a condition that the instantaneous phase variation at the detector not exceed ± 90°, since this is the maximum range over which the detector operates as a phase control device. Since the frequency division reduces the phase variation due to modulation to less than 24°, the system is always within the control of the phase detector when the system is under synchronization. As a matter of fact, it is possible to exceed continuous 200-percent modulation and still be in control.

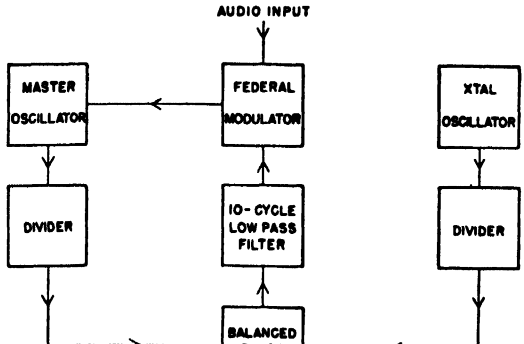


Fig. 11–17. Basic block diagram of Federal CFS modulator system.

The output circuit of the phase detector is essentially an integrator and low-pass 10-cycle filter that responds only to slow mean frequency drifts and removes the residual modulation.

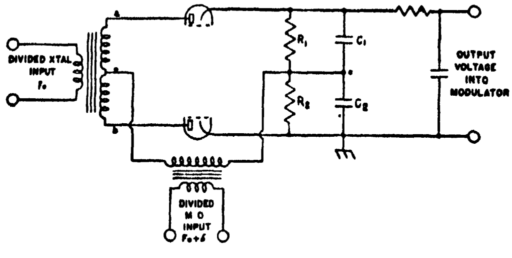


FIG. 11–18. Basic circuit of balanced phase detector.

It can be shown that under conditions of synchronization the output voltage of the balanced phase detector is given by

$$\begin{aligned} V_{\text{output}} &= |V_{ca}| - |V_{cb}| \\ &= 1.414V_{oc}[\sqrt{1 + \cos\delta} - \sqrt{1 - \cos\delta}] \end{aligned}$$

where δ is the phase angle between the divided master oscillator input and the divided crystal input. This is shown in Figure 11–19. The output voltage is plotted against δ in Figure 11–20.

The physical picture of the action of the balanced phase detector may be considered as the action of two peak-reading diode detector circuits whose outputs are combined in opposition. V_{ca} is the peak voltage acting on the upper diode and V_{cb} is the peak voltage acting on the lower diode. The time constants of the output network R_1C_1 and R_2C_2 are high enough to prevent any appreciable delay in the peak voltage during the time when the diode is not conducting. If 90° phase between the two identical frequencies is assumed, V_{ca} is equal to V_{cb} and their difference gives zero output voltage. This is the normal operating condition. Any attempt at slow drift of the master oscillator frequency will shift the phase in a direction to give a correcting output voltage to the Federal modulator. This voltage will change the injected capacitance so that the frequency will remain the same. Therefore, we may operate at any point within the region of control of the S curve, and the system will be in synchronization. In the same manner, should any of the parameters of the oscillator circuit change, normally causing a change in frequency, the phase will shift to compensate for the parameter shift and the frequency will remain constant.

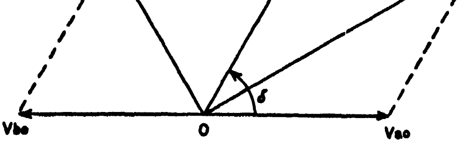


FIG. 11–19. Vector diagram of phase detector.

It has been previously noted that the phase swing due to modulation is well within the limits of control of the balanced phase detector. Since the lowest modulating frequency is 30 cycles, the 10-cycle, low-pass filter following the detector removes the residual modulation.

To effect the frequency division, the frequency-modulated master oscillator is fed through a total of six multivibrator frequency divider circuits to reduce the original 3.7–4.5 mc carrier frequency 256 times to 14.3–17.6 kc. In a similar manner the crystal frequency of 114.5–140.7 kc is divided by a factor of 8 in two multivibrator circuits to the common 14.3–17.6 kc value. All multivibrators are of the well known Abraham-Bloch type, which divides the applied frequency accurately by means of extremely simple and reliable circuits.

The carrier is controlled by a crystal mounted in a Bliley type TC–93 oven holder. The frequency of this crystal is 1/768 of that of the carrier.

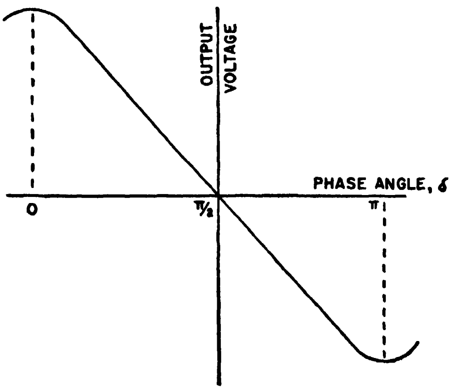


FIG. 11–20. Response characteristic of phase detector.

11–12. RCA Type BTF F-M Transmitters—The RCA type BTF series consists of three transmitters with power ratings of 250 watts, 1000 watts and 3000 watts, which employ new circuit features including a new exciter of unique design, a new tube especially designed for 100-mc operation, and a grounded-grid amplifier. All transmitters are made up of basic units 25 inches square by 84 inches high, and so designed that adding an amplifier in any power category entails very little equipment or cost. Each unit has vertical chassis construction providing unimpeded up-draft ventilation; full length, full width doors provide quick access to all parts. The units are dust-proof, since the only openings are into cabinets through dust filters in the base, and each unit is provided with blowers in the base or ventilating fans in the top.

11–12a. Add-on Amplifier Design—As mentioned previously, an increase in power can be accomplished readily due to the fact that each successive power category is formed by adding an amplifier to the next lower-powered unit. Thus, the BTF-250 (250-watt) transmitter plus an amplifier becomes the BTF-1C (1000-watt) transmitter; the BTF-1C plus an amplifier becomes the BTF-3B (3000-watt) transmitter, and so on.

Ordinarily, it would not be economical to add an amplifier for a three-to-one step-up in power because conventional tubes and circuits are usually designed for, and operate most efficiently at, step-up ratios of the order of ten-to-one. As a result, with conventional amplifiers, the combination of a low-powered unit plus an amplifier costs more than a unit built originally for the higher power. However, when grounded-grid amplifiers are used, as in the new RCA F-M transmitters, this is not true; for with grounded-grid circuits, the driver stages also contribute to the actual antenna output of the transmitter. Thus, a much smaller amplifier tube can be used than in conventional circuits, and a three-to-one step-up becomes more economical and more practical. The new RCA F-M transmitters have been designed to facilitate the addition of amplifiers to increase power.

It is worth noting also, that another feature of the new F-M transmitters adds naturally to the ease of power increases. This is the aptly titled "Multi-Unit" construction whereby all of these transmitters are made up of standard cabinet units which go together like building blocks. With this type of construction, the addition of amplifier units is relatively easy. The extra units fit directly on the original units; no additional air or wiring ducts are required. And, not the least important, the over-all installation has a matching appearance; it looks like an equipment designed originally as a single unit, which, as a matter of fact, it was.

Even for the station that never actually makes use of the add-on amplifier feature, it has some value. This is because standardization greatly increases the quantity of low-power units manufactured and thereby substantially reduces the cost of each.

11-12b. Specifications of RCA Type BTF-250A Transmitter—The RCA type BTF-250A transmitter is designed for operation at output powers of 50 watts to 250 watts. While this transmitter is the smallest of the new RCA F-M transmitters, it incorporates the same circuits as those in the larger transmitters, uses the same type of components and is built to the same standards as the larger equipments. In fact, this same unit is used, with minor modifications, as the driver unit of the high-powered transmitters. Thus it makes available to "community" stations and educational stations a transmitter which, although of relatively low power, will nevertheless meet the same standards of performance and reliability as the largest and most deluxe types. Moreover, because of the savings effected in manufacturing standardized units in large quantities, it costs no more than similar power equipments which are built in much less substantial manner.

Electrically the BTF-250A consists of a standard exciter followed by two r-f amplifier stages. The output frequency of the exciter falls in the range of 44 to 54 mc. This is doubled to the final operating frequency in the first 4-125A stage. This stage drives a final amplifier which employs two type 4-125A tubes in parallel. There are two rectifiers; a low-voltage unit utilizing one RCA 5U4G and a high voltage unit employing two RCA 866A/866's.

Mechanically the BTF-250A consists of a single cabinet of the type standardized for all RCA F-M transmitters. In this cabinet are the F-M exciter unit, its power supply, the r-f amplifiers, their power supplies, and the necessary control circuits. The schematic diagram is shown in Figure 11-21. The performance specifications follow:

1. *Frequency range:* Any specified frequency between 88 and 108 mc.
2. *Power output (into transmission line):* 50 to 250 watts.
3. *R-f output impedance:* 35 to 75 ohms.
4. *Carrier frequency stability:* Deviation less than 2000 cps.
5. *Modulation capability:* ± 100 kc.
6. *Audio input impedance:* 600 ohms.
   Average program level: + 4 ± 2 vu.
   100% modulation level: + 12 ± 2 dbm.
7. *Audio-frequency response (30 to 15,000 cps, 1000 cps reference):* Within ± 1 db.
8. *Audio-frequency distortion (30 to 15,000 cps, including all harmonics up to 30 kc/s at ± 75 kc swing):* Less than 1.5% rms.
9. *F-M noise level, below ± 75 kc swing:* 65 db.
10. *A-M noise level, below 100% amplitude modulation:* 50 db.
11. *Power line requirements (transmitter)*
    Line voltage: 208/230 volts.
    Frequency: 50/60 cps.
    Power consumption: 1050 watts.
12. *Power line requirements (crystal heaters)*
    Line voltage: 115 volts.
    Frequency: 50/60 cps.
    Power consumption: 28 watts.

11-12c. Specifications of RCA Type BTF-1C Transmitter—The RCA type BTF-1C transmitter is intended for operation at output powers of 250 watts to 1000 watts. It is built in the same manner as the larger RCA F-M transmitters, uses the same circuits and components, and can, at reasonable cost, be increased in power by addition of standard amplifier units. It is well suited for the requirements of stations in metropolitan centers of medium size and may also be used by larger educational stations when the very highest standards of performance and reliability are desired.

The electrical circuits of the BTF-1C are similar to those of the BTF-250A with the addition of an

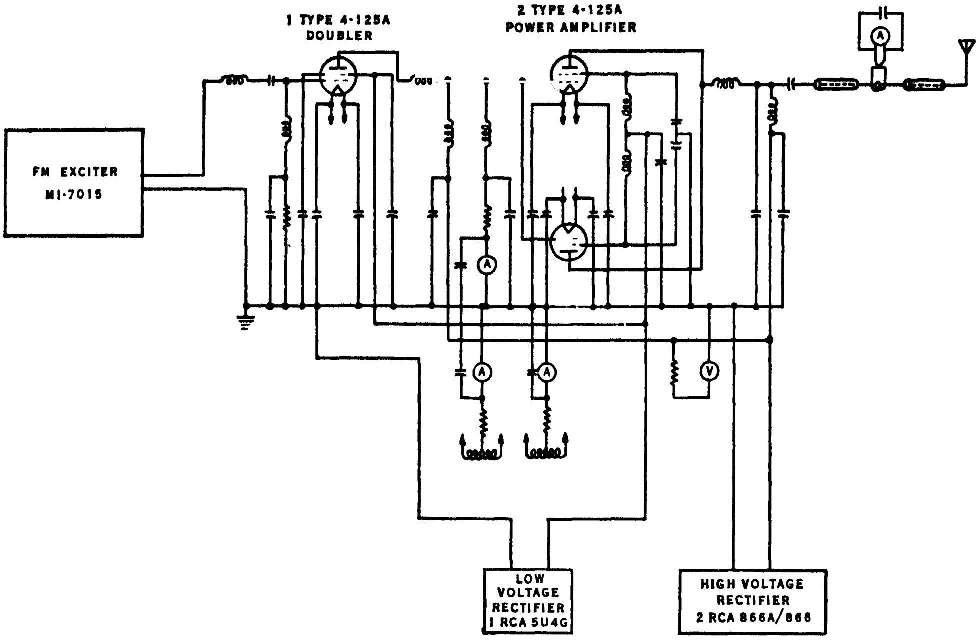


Fig. 11–21. Simplified schematic diagram of the RCA BTF 250A transmitter.

extra amplifier stage to give increased power. A standard exciter is followed by a type 4–125A as a doubler. This doubler is followed by an intermediate r-f stage employing two type 4–125A's in parallel. This stage acts as the driver for a grounded-grid amplifier stage in which one of the new RCA-7C24's is used to furnish the required power to the antenna transmission line. In addition, there is a low-power rectifier using one RCA 5U4G and a high-voltage rectifier using four RCA 8008's.

All the components of the BTF-1C are mounted in two of the new standard transmitter cabinets. In the right-hand cabinet are mounted the high-voltage rectifier and the standard F-M exciter unit; in the left-hand cabinet, the r-f amplifiers. Additional space in this cabinet is utilized when it is desired to increase output power above 1000 watts.

The controls on the right-hand door are the filament rheostat and filament and plate switches. The controls located on the left-hand door are for tuning purposes. From right to left they tune successive stages. The final control on the extreme left varies the power output from 250 to 1000 watts, the level being indicated in percent by the

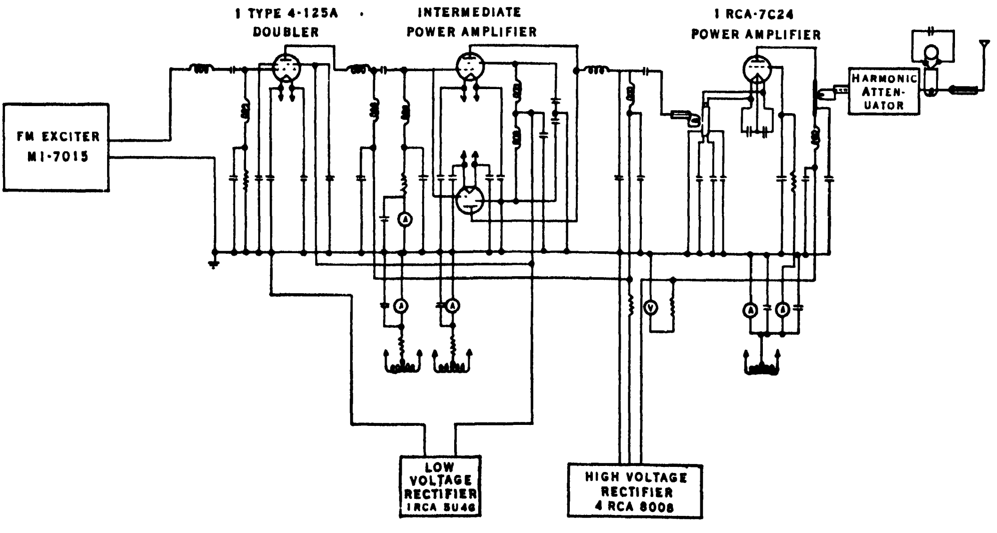


Fig. 11–22. Simplified schematic diagram of the RCA BTF-1C transmitter.

power output meter above, which is adjusted to read 100 percent when the output is determined for the specified coverage. See Figure 11-22 for simplified schematic diagram. The performance specifications follow:

Frequency range: Any specified frequency between 88 and 108 mc.

Power output (into transmission line): 250 to 1000 watts.

R-f output impedance: 35 to 75 ohms.

Carrier frequency stability: Deviation less than 2000 cps.

Modulation capability: ± 100 kc.

Audio input impedance: 600 ohms.

Average program level: + 4 ± 2 vu.

100% modulation level: + 12 ± 2 dbm.

Audio-frequency response (30 to 15,000 *cps,* 1000 *cps reference):* Within ± 1 db.

*Audio-frequency distortion (*30 *to* 15,000 *cps, including all harmonics up to* 30 *kc/s at ±75 kc):* Less than 1.5% rms.

F-M noise level, below ± 75 kc, swing: 65 db.

A-M noise level, below 100% *amplitude modulation:* 50 db.

Power line requirements (transmitter)

Line voltage: 208/230 volts.

Frequency (50 cps available at slightly higher cost): 50 or 60 cps.

Instantaneous regulation (maximum): 5%.

Power consumption (approximate): 3000 watts.

Power line requirements (crystal heaters)

Line voltage: 115 volts.

Frequency: 50/60 cps.

Power consumption: 28 watts.

11-12d. Specifications of RCA Type BTF-3B Transmitter—The RCA type BTF-3B transmitter is suitable for stations requiring a power output (to the transmission line) of 1000 to 3000 watts. Circuits, components, and construction are essentially the same as those of the other BTF transmitters. It is probable that this transmitter will be used by many stations in metropolitan areas, and this possibility has been given special consideration in the design. Space in which a spare exciter unit may be mounted is one of the features.

Electrically, the BTF-3B has the same circuits as the BTF-1C plus an additional amplifier stage. The standard exciter unit is followed by a doubler stage using a type 4-125A and two r-f amplifier stages using, respectively, two type 4-125A's and an RCA 7C24 (the latter operating as a grounded-grid amplifier). This stage acts as the driver for a final output stage which consists of another RCA 7C24, also using a grounded-grid circuit. The use of the same size tube in both driver and output stages is made practical by the fact that with the grounded-grid circuit the driver stage contributes a substantial share of the output power, thereby making it possible to use a much smaller tube in the output stage than would be required with a conventional grounded-filament circuit. Rectifiers in the BTF-3B include a low-voltage unit using one RCA 5U4G and a high-voltage unit using six RCA 8008's. The control circuit includes automatic starting and recycling. A schematic circuit of the BTF-3B transmitter is shown in Figure 11-23.

Structurally, the BTF-3B consists of three of the standard transmitter cabinets. The exciter (and a spare, if used) and its power supply are located in the center cabinet. The r-f amplifier circuits are located in the left-hand cabinet, and the high-voltage power supply and control circuits are in the right-hand cabinet. The performance specifications follow:

Frequency range: Any specified frequency between 88 and 108 mc.

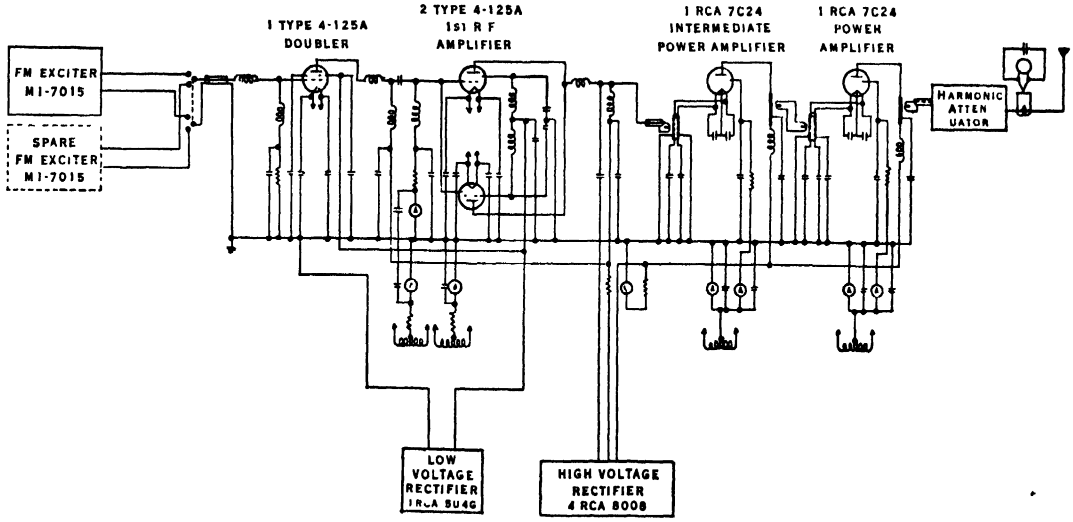


Fig. 11-23. Simplified schematic diagram of the RCA BTF-3B transmitter.

Power output (into transmission line): 1000 to 3000 watts.

R-f output impedance: 35 to 75 ohms.

Carrier frequency stability: Deviation less than 2000 cps.

Modulation capability: ± 100 kc.

Audio input impedance: 600 ohms.

Average program level: + 4 ± 2 vu.

100% modulation level: + 12 ± 2 dbm.

Audio-frequency response (30 to 15,000 cps, 1000 cps reference) uniform within: ± 1 db.

Audio-frequency distortion (30 to 15,000 cps, including all harmonics up to 30 kc/s at ± 75 kc swing): Less than 1.5% rms.

F-M noise level, below ± 75 kc swing: 65 db.

A-M noise level, below 100% amplitude modulation: 50 db.

Power line requirement (transmitter)

Line voltage: 208/230 volts.

Frequency: 50 or 60 cps.

Power consumption (approximate): 8300 watts.

Power line requirements (crystal heaters)

Line voltage: 115 volts.

Frequency: 50/60 cps.

Power consumption: 28 watts.

11-12e. Power Circuit Features—In the BTF transmitters, all power circuits are protected by magnetically or thermally tripped circuit-breaker switches. These circuit breakers automatically open under overload conditions and thus isolate the fault from the a-c bus. They are used in high power, filament, blower, and low-power circuits. Their use eliminates the delay and danger involved in replacing fuses in these circuits. The only fuses in these transmitters are the two in the crystal heater circuits for the exciter unit. In the 3 kw transmitter, high-speed overload relays are provided in the high power circuits in order to give additional protection to expensive components. In all transmitters, an interlocking control prevents the application of plate power until the rectifier filaments have reached operating temperature.

In the BTF-3B both manual and automatic starting are provided. When in the Automatic position, a 3-shot recycling sequence is provided which automatically returns the transmitter to the air up to three times in case of repeated overloads and then, if the overload condition persists, automatically shuts the transmitter down. The carrier monitor is connected to this circuit; hence, any arc on the transmission line will cause the transmitter to shut down momentarily to permit the arc to clear. A special hold-in circuit permits the transmitter to return instantly to the air in case of a momentary power line failure, thus avoiding the 30-second delay required for the plate time-delay relay to close. A power reduction switch located in the primary circuit of the main rectifier provides a reduced power position for tune-up and emergency operation.

In the BTF-3B transmitter a new type rectifier tube, the RCA 8008, is used. In prewar transmitters of this power category 872 or 872A's were used. While these tubes have ratings sufficient for the service it was found that many transmitter outages resulted from the rectifier failures (because of the number of these tubes involved). Since the cost of these tubes is relatively small, it seemed worthwhile to consider means of obtaining longer life. However, to go to the next larger size would entail using tubes altogether too large. This problem has been solved by the production of the RCA 8008. Essentially the same internally as the 872/872A, the 8008 has a larger base and pins, and an improved anode cap. It is expected to give much less trouble and considerably improved life.

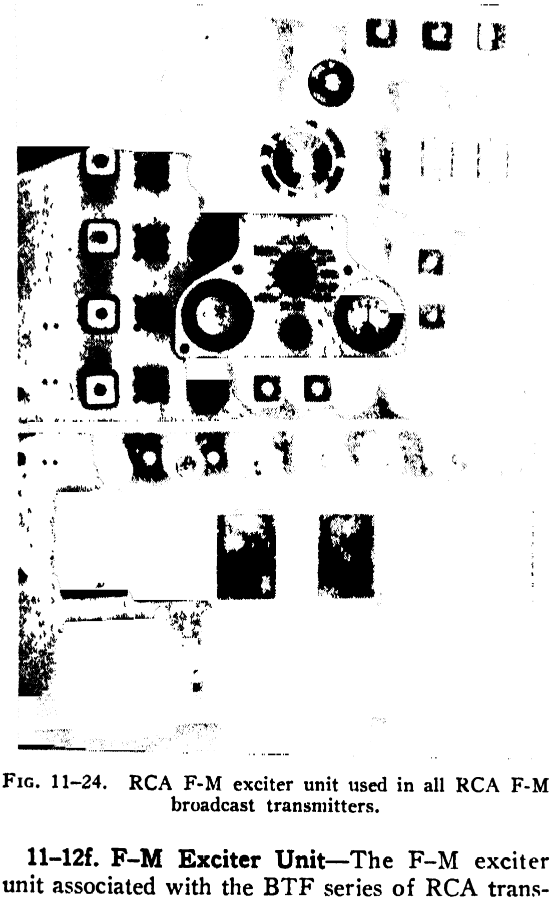


FIG. 11-24. RCA F-M exciter unit used in all RCA F-M broadcast transmitters.

11-12f. F-M Exciter Unit—The F-M exciter unit associated with the BTF series of RCA transmitters consists of two vertical panels, as shown in Figure 11-24, one panel of which contains the r-f modulator circuits and the other the regulated power supply. Electrically, the exciter unit includes all of the frequency generating, modulating, and frequency multiplying circuits of the transmitter except the final doubler. Modulation is accomplished by the reactance or "direct" method as described in Chapter 7. However, a new method of frequency control is employed having operational advantages over the former method.

It will be recalled from Chapter 7 that it is necessary to compensate for the drift in frequency of the master oscillator by a crystal-controlled oscillator used in connection with a mixer and discriminator circuit. The crystal oscillator is operated at a frequency 1 mc higher than the master oscillator, and the beat note developed between the two oscillators rectified in a mixer tube and fed into a discriminator in such a manner that any fluctuation in the 1-mc frequency caused by variation of the master oscillator frequency is converted to a varying d-c potential. After filtering, to remove rapid fluctuations such as would be caused by modulation, this d-c potential is used to control the grid potential of one of the reactance tubes with such polarity as to reduce any change in frequency of the master oscillator.

The disadvantage of such a system is that the d-c control potential is dependent on the discriminator characteristic and it fluctuates because of changes of contact potential of the rectifier required for operation of the discriminator.

This disadvantage can be offset in part by placing the master oscillator, the reactance tube modulator, and the discriminator in a temperature controlled oven; however, the oven tends to offset the desirable feature of circuit simplicity as it makes access to circuit elements difficult and time consuming.

The operation of the RCA FM exciter unit has been described by N. J. Oman, of the RCA Transmitter Engineering Department, as follows[2]:

> "Two balanced modulators are set up to obtain in the output of each a beat frequency corresponding to the difference between the crystal reference frequency and that of the master oscillator. The signal output from the crystal oscillator divides and feeds through phase shift networks designed to give a 90° displacement in phase between the inputs to the two modulators. The signal from the master oscillator is of the same phase in both modulators. It is rather obvious that the 90° displacement in the crystal oscillator signal will result in a 90° displacement of the beat frequencies in the output circuits of the two modulators. Not so obvious, but nevertheless true, the direction of rotation of the two 90° vectors, that might be considered as generating the two-beat frequency outputs, changes from clockwise to counterclockwise depending on whether the master oscillator frequency is higher or lower than the crystal frequency. In other words, there is a reversal of one phase of the two-phase output of the two modulators when the master oscillator frequency passes through zero beat with the crystal frequency. If the two-phase output of the two modulators is utilized to energize the field windings of a two-phase motor, the direction of rotation of the motor shaft will be clockwise if the master oscillator frequency is higher than that of the crystal oscillator, and counterclockwise if the master oscillator frequency is lower than that of the crystal. The motor can therefore be used to turn a capacity or other tuning means to effect a correction of the master oscillator frequency should it depart from that of the crystal oscillator. A preliminary arrangement of this kind is illustrated in Figure 11-27.

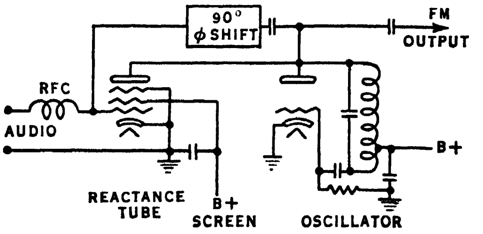
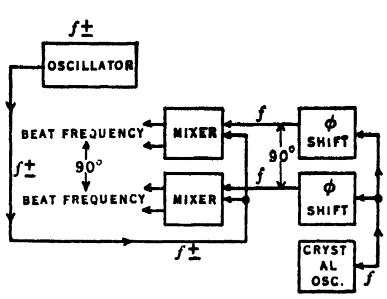
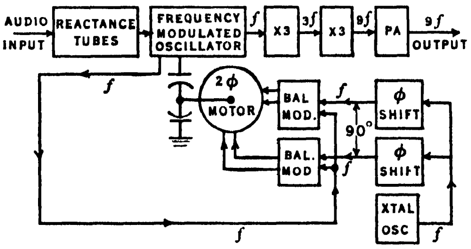


Fig. 11-25. Simplified diagram of the reactance modulator circuit developed by RCA. This circuit accomplishes frequency modulation directly.



FUNDAMENTAL FREQUENCY CONTROL CIRCUIT

Fig. 11-26. This is the basic control circuit used in the exciter. Two beat frequency voltages, 90° out of phase, are used to drive a two-phase motor which controls the position of the frequency-determining condenser.



PRELIMINARY FREQUENCY CONTROL
FM EXCITER

Fig. 11-27. Block diagram of the preliminary form of the exciter unit. In this arrangement the crystal-controlled oscillator operates in the 4.5 to 6.0 mc band, thus permitting direct comparison with modulated oscillator frequency.

> "If the frequency control is to be a precision device the method of drive (or the mechanical coupling) between the motor and the tuning element is very important. It will be recognized that the system, as described so far, has a very desirable feature in that the rate of rotation of the free motor shaft would, within limits, be proportional to the difference of the oscillator frequencies, as opposed to an on-off device that would give full motor speed up to correct frequency. This characteristic of the system helps reduce difficulties with hunting so prevalent with automatic controls of similar type. In preliminary tests of this control a worm-and-pinion speed-reduction gear was used between motor and tuning condenser. This method of drive proved to be unsatisfactory. When sudden large frequency corrections were required, a relatively long time was consumed by

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[2] "A New FM Exciter Unit of Greatly Improved Performance," N. J. Oman, *Broadcast News*, No. 42, January, 1946.

the operation. For small frequency deviations the action was sluggish, since the motor turned very slowly. It had first to take up lost motion in the gearing and it had to develop enough torque to overcome static friction.

"To correct the above-mentioned condition the tuning condenser rotor was mounted on an insulator on one end of the motor shaft. The fixed plates of the condenser were split in half, one half was grounded, the other half was connected to the master oscillator plate circuit. This construction eliminates all backlash or lost motion, and also eliminates friction other than that of the motor bearings. With this construction the motor is never required to turn more than ± 45° to include the full range of control, and friction is reduced to a minimum. The action is fast and positive. The motor can easily follow the slightest variations in frequency. The rate of frequency correction is limited only by the requirement of not causing demodulation of the lowest signal frequency.

"Several types of two-phase motors were considered for the control. One was of synchronous type with a permanent magnet rotor. This motor provided very accurate control, but none tested would start if the initial frequency exceeded 60 cycles-per-second. No damping could be used with this synchronous motor and inertia had to be kept low so as not to hamper starting. A second type tested was an induction motor. This had torque enough to start at frequencies up to 1000 cycles-per-second. Further tests with this induction motor, with viscous damper and direct-mounted condenser, demonstrated that it would respond to the slightest rotation of its magnetic field. This motor, therefore, was selected as most suitable for the control.

"Since the limit on the control range with this system is the high frequency response limit of the motor, an increase in the range of control can be obtained by dividing the modulated oscillator frequency, so that it can be compared to a crystal oscillator at a lower frequency. The range of control can thus be increased by a factor equal to the division in frequency. There are several ways of accomplishing the required frequency division. One is by the use of frequency dividing stages employing the principle of regenerative modulation, whereby a subharmonic is obtained by a modulation process. Since the output energy is obtained by a modulation process involving both the input and output waves, the output signal will appear only when an input wave is applied and bears a fixed frequency ratio with respect to it. The circuit makes use of copper oxide modulators and the output circuit is tuned to one-half the input frequency. The tuned circuits are made sufficiently broad to permit substantial output voltage over a frequency range of ± 1.5%. The disadvantage of this circuit is the number of tubes and circuits required.

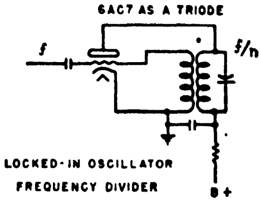

Fig. 11–28. Circuit of the Beer's locked-in oscillator as used in the exciter unit. This circuit permits division ratios of as much as five-to-one, thereby reducing the number of frequency divider stages which are required.

"Another possible way to obtain frequency division would be to make use of multi-vibrators. The wave shape would be poor, but it would be possible to get higher division per stage.

"The third circuit considered was the locked-in oscillator frequency divider as shown in Figure 11–28. This circuit reduces the number of circuit components to a minimum. The wave shape of the output is sufficiently good for the purpose. It will cover the tuning range required for the exciter by means of an adjustable iron slug in the coil. The lock-in range may be as high as ± 5%.

"Having selected a circuit for frequency division the next consideration was to fix the frequency at which the comparison of frequencies was to be made. During the war the RCA crystal group developed a crystal and holder designed to operate in the frequency range of 90 to 125 kc. The performance of these units has been very good and they, therefore, were selected for use as a frequency standard.

"A preliminary test of the performance of the frequency control with frequency comparison made at 100 kc gave excellent performance, except for loss of control in the presence of tone frequency modulation when the modulating frequency was below one hundred cycles.

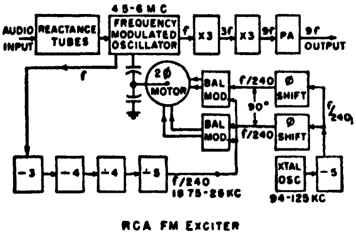

Fig. 11–29. Block diagram of the final arrangement of the exciter unit. The crystal-controlled oscillator operates in the 94 to 125 kc band.

A fundamental characteristic of frequency modulation is that the power output (or the energy in the modulated signal) does not change with the degree of modulation. However, as the amount of modulation is increased from zero, there is a transfer of power from the carrier to the sidebands lying above and below the carrier frequency. This effect continues with increasing modulation until a point is reached where all the energy is in sidebands and there is no power in the carrier. With further increase in modulation, or frequency swing, the carrier again reappears. With the ± 75 kc swing of frequency used for broadcasting, there are several cycles of this effect at low modulating frequencies. In early experiments where the frequency comparison was made at 5 mc (Figure 11–27) this phenomenon showed only as a loss of torque in the motor.

"Theoretically we should have been able to find conditions of modulating frequency and degrees of modulation where there was no torque. Actually these points were so critical and sharply defined that it required some care to find them. In actual operation with program modulation, the condition of no-torque would not exist long enough to lose control.

"The effect of frequency division is to reduce the swing of frequency with modulation, along with the reduction of carrier frequency. This is carried far enough (when the frequency comparison is made at 100 kc) that carrier loss occurs only at frequencies of modulation below 100 cycles and for 100 cycle modulation only with full frequency swing of 100% modulation.

"This effect was not serious with program modulation, but in taking performance data on a transmitter with tone modulation it would be apparent. An additional division by 5, to 20 kc, eliminates this trouble except for modulation below 20 cycles which is low enough to be neglected.

"The final circuit of the new exciter is shown in the block diagram of Figure 11-29. The tubes in the top row are, from left to right, the reactance tubes, modulated oscillator, a frequency tripler, followed by a second tripler, and a power amplifier. The power amplifier is used to get sufficient power to feed through a transmission line to the main transmitter. The output frequency of the exciter will fall in the range of 40.5 to 54 mc. With a multiplication of two in the main transmitter a frequency range of 81 to 108 mc is provided.

"A lead shown at the left in Figure 11-29 conducts synchronizing voltage from the modulated oscillator to the first divider at the lower left. The dividers are set up as shown with four stages, giving a total division of 240. This places the output frequency of the last divider in the range of 18.75 to 25 kc. The output of the last divider is connected directly to the two balanced modulators.

"The crystal oscillator shown at the lower right may operate at any frequency between 94 and 125 kc. This is accomplished without the use of any tuning adjustments. The crystal output synchronizes a divider at one-fifth the crystal frequency. This frequency is also fed to the balanced modulators, but in this case a phase shifting network is included in the lead to each modulator adjusted to maintain a 90° displacement in phase between the modulators over the range of frequencies involved. The only tuning required in the crystal or reference frequency part of the circuit is to set the slug in the divider so that its frequency is locked to one-fifth of the crystal frequency.

"Each balanced modulator has a pair of 6L6 tubes biased to cut off and connected push-pull. The induction motor used has high impedance center-tapped windings on each phase so that it can work in the plate circuit of the balanced modulator tubes without the use of matching transformers. In this way the motor receives full voltage down to d-c beat frequency. The need for this is evident when one considers that the motor must respond to a beat frequency lower than one part in a million at 20 kc. This comes out to be .02 cycles-per-second or 1.2 cycles-per-minute. This rather surprising performance from an induction motor is largely made possible by the elimination of load on the motor. The absence of gearing and the use of viscous damping establish a condition in which there is little or no resistance to small or slow rotation of the motor shaft. The motor responds to frequencies up to 1000 cycles whereas the motors used in previous exciters of this general type were limited to 60 cycles, thereby requiring comparison at about 5 kc instead of the higher frequency.

"The operation of the circuits may be checked easily and rapidly by means of test equipment built into the exciter. A cathode-ray oscilloscope, with a selector switch, is provided making it possible to check the operation of each divider and also the tripler amplifiers by means of lissagous figures. A three position selector switch enables the operator to apply a d-c potential to either reactance tube grid, causing the frequency of the modulated oscillator to shift high or low over a range considerably in excess of the range encountered due to ambient temperature, humidity, or line voltage variation. The behavior of the frequency control motor and the relative rotation of the shaft required to correct the artificial frequency shift may be observed on a dial on the motor shaft. This operation gives a rapid check of the performance of the reactance tubes and the frequency control mechanism. A meter is provided to read the plate current of the reactance tubes and the modulated oscillator. A buzzer, operated by a cam switch on the frequency control capacitor shaft, gives warning if for any reason the frequency control is about to fail because of passing through maximum or minimum capacity. The buzzer will sound only if there is maladjustment of oscillator tuning control or for the failure of all but a few of the frequency control circuit elements.

"The accuracy of the frequency control is limited by the heat cycle of the crystal oven. On test this effect shows a regular variation of ± 40 cycles at 100 mc as the thermostat of the crystal oven goes on and off. The control action is smooth and rapid. There are no critical adjustments. The range of control can be as high as ± 1000 cycles at 20 kc or ± 5%. At 100 mc this amounts to ± 5 mc.

"In case of failure of the frequency control during a program, operation can be continued with manual frequency control by locking the motor shaft and adjusting frequency with a vernier tuning control on the master oscillator tank coil.

"The distortion in the frequency-modulated output of the exciter is of the order of 0.5% for modulating frequencies from 30 cycles to 15,000 cycles. The noise level in the output is 74 db below 100% modulation."

11-12g. Grounded-Grid Amplifiers—Grounded-grid amplifiers are used in all of the BTF transmitters of powers above 250 watts. Amplifiers of this type are extremely stable, and in this respect are superior to either conventional triode circuits or those employing screen grid tubes. This fact is particularly important at frequencies above 50 mc where circuits must be kept simple and where feedback, either through tube or circuit, is particularly hard to control. They require no neutralizing, and the associated circuits are simpler and require fewer components. Moreover, more power output can be obtained from an amplifier using a tube of a given size, thereby making possible the use of smaller, less expensive tubes with a consequent reduction in overall operating cost.

In the grounded-grid amplifier, as the name indicates, the grid of the tube is at r-f ground potential (instead of the filament as in conventional amplifiers). Normal bias is necessary and is supplied in the same manner as that of the conventional grounded-cathode circuit. Since the grid is at ground potential, it performs the dual function of acting as the control grid, and as a screen between plate and cathode circuits. It follows that if a tube which has been properly designed to take advantage of the screening action is used, no neutralizing circuits are required.

Grounded-grid amplifiers require more power from the driver stage than do conventional amplifiers. This, however, does not represent a loss of efficiency, for all the extra driver power actually appears in the plate circuit of the amplifier tube as output power. In other words, in this type of amplifier, the actual output power comes partly from the amplifier stage and partly from the driver stage. This characteristic is used to advantage in the BTF transmitters, since it makes possible the efficient use of amplifiers of three-to-one power step-up ratio. Moreover, it allows the same type of tube to be used in the 1-kw and 3-kw stages.

11-13. The Grounded-grid Amplifier—A schematic circuit of the grounded-grid amplifier is shown in Figure 11-30. Fundamentally, the

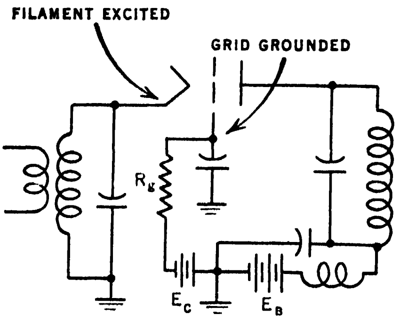

Fig. 11–30. Grounded-grid amplifier.

grounded-grid amplifier can be represented as two generators in series as shown in Figure 11–31. In this case, E_g is the input voltage and E_p is the plate to cathode voltage. The driver E_g is required to furnish power to the load, to the grid losses of the tube, and to the bias resistor. The last two can be considered as R_g of Figure 11–31. The generator E_p supplies no power to R_g; hence neutralization is not usually required.

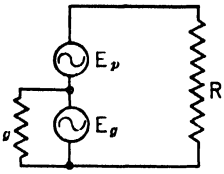

Fig. 11–31. The grounded-grid amplifier can be represented as two generators in series as shown above.

Inasmuch as the driver supplies the grid losses as well as the load with power, from the driver viewpoint, the load presented becomes two resistances in parallel,

$$R_g \text{ and } \frac{E_g}{I_p} = R_0$$

as shown in Figure 11–32.

R_g, representing the grid losses, is substantially a constant resistance, if E_g is constant, but the value of R_0 varies inversely as the plate load current, becoming infinite if no load current flows (plate circuit open) and being the lower of the two resistances at normal load. The total resistance presented to the driver varies inversely as the plate load current, and since the driver is required to develop substantially the same value of E_g into lower resistance, more power must be supplied by the driver. Consequently, it can be seen that the circuit is highly degenerative, requiring the driver to supply increased power in proportion to any increase in plate load current. This increase in driver power is reflected in the plate circuit as increased power output.

11–13a. Neutralization at High Frequencies—It may be necessary to neutralize the grounded-grid amplifier at high frequencies for the following reasons:

1. The presence of inductance between the active grid element and the common returns of the input and output circuit (due to tube lead inductance).
2. Feedback through the plate-to-cathode capacitance (if of any appreciable magnitude).

With regard to (1), the inductance from the active portion of the grid-to-ground (tube lead) will usually be small enough to be ignored, since it will have a tendency to neutralize the plate-to-cathode capacitance. With respect to (2), the cathode-to-plate capacitance of tubes designed for grounded-grid operation will usually be low enough so neutralization will be unnecessary. From the standpoint of stability, a certain amount of capacitive feedback may be tolerated since the inherent degeneration characteristics of the circuit causes the input impedance to be lower than in the conventional amplifier; consequently, considerable more power transfer from output to input would be required to sustain oscillation.

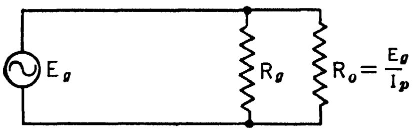

Fig. 11–32. The load presented to the driver of a grounded-grid amplifier can be represented as two resistances in parallel as shown above.

As the frequency is increased, a point will be reached where either of the above effects may be sufficient to cause the feedback energy to become sufficient to overcome the degeneration. Neutralization will then be necessary.

11–13b. Neutralization Procedure—Under certain conditions of operation, neutralization of the grounded-grid amplifier can be accomplished successfully only by removing the filament power from the amplifier tube, since during operation the cathode is driven negative (rather than the grid positive) and the plate and grid will have a positive potential relation to the cathode over part of the r-f excitation cycle. Therefore, if a path is provided for d-c plate current flow (plate supply grounded or left with rectifier filament excited) the plate ammeter will indicate plate current even though neutralization is complete. Moreover, at the same time the a-c components flow through the plate circuit and cathode circuits, developing a-c voltage in both of these circuits. The a-c component of power will be delivered to the load while the d-c component is supplied to the rectifier. Consequently, under these conditions of operation, the output power cannot be reduced to zero by the usual method of neutralization and it becomes necessary to remove the filament heating power to accomplish neutralization. Minimum feedback by this method of neutralization (cold filament) may not be exact when the filaments are reheated due to changes in tube capacity and it may be necessary to check the neutralization again by observing the behavior of the tube under operating conditions.

The usual observation can be made to check neutralization, that is, observing if maximum grid current coincides with minimum plate current.

11–13c. Plate Circuit Adjustments—Since a-c plate current appears in the amplifier plate circuit when r-f drive is applied to the grid circuit, means are provided to tune the plate circuit to resonance, and to a certain extent to adjust the loading before applying plate voltage to the amplifier.

It has been previously explained that the grounded-grid amplifier is highly degenerative; consequently, the driver power demands will vary over a wide range according to the amplifier plate input, hence the drive must be readjusted for each value of d-c grid current.

11–13d. Efficiency—Since the driver supplies power to the output of a grounded-grid amplifier, the usual equation for amplifier efficiency,

$$\text{Efficiency} = \frac{P'_{\text{out}}}{P_{\text{in}}} \times 100 \text{ percent}$$

(where P'_{out} is the power output as a grounded-grid amplifier and P_{in} is the power input), must be corrected to take care of the power contributed to the output by the driver.

Hence the true efficiency may be represented by:

Efficiency (grounded-grid)

$$= \frac{P'_{\text{out}} - P_{\text{out}}\left(\frac{E_g}{E_p}\right)}{P_{\text{in}}} \times 100\%$$

with the power contributed by the driver being represented by the factor

$$P_{\text{out}}\left(\frac{E_g}{E_p}\right).$$

This quantity is a function of the tube parameters and operating conditions, varying directly as the amplifier plate current.

11–13e. Amplitude Modulation—While it does not apply to transmitters described in this chapter, it should be pointed out that when the grounded-grid amplifier is plate modulated, it is necessary to modulate the driver simultaneously in order to limit distortion. Distortion arises in a grounded-grid amplifier from three sources: (1) nonlinearity of the power amplifier, (2) nonlinearity of the driver, which is introduced directly into the output, and (3) reaction of the nonlinear elements on the modulator.

Distortion arising from (1) can be reduced to a minimum by providing 60-percent modulation to the driver whereas it is necessary to use 100-percent modulation of the driver to reduce the second source of distortion to a minimum. This same ratio holds for the third source of distortion. Because of these conflicting driver modulation requirements, experience shows that 80-percent modulation is a good compromise to insure a minimum over-all distortion value when the three distortion factors mentioned above are considered as being added to the over-all distortion product.

CHAPTER 12

TELEVISION[1]

12-1. Introduction—The treatment accorded to television in this chapter is intended primarily to provide a clear explanation for the student and for the operator of television equipment. Inasmuch as television is a relatively new art, a brief description of the general principles of television operation is presented first. As is common with such new art, television has led to the development of many novel types of circuits not heretofore used in radio practice and a new vocabulary has arisen with these developments. Following the general discussion will be found a group of definitions of some of these television terms, after which there will follow certain details elaborating upon the various circuits and functions of television equipment common to the broadcasting station, with a brief section on receiver characteristics and general propagation.

Electronic television is accomplished by converting pictures into corresponding electric impulses, transmitting these impulses and utilizing the signals to vary the intensity of an electron stream in the receiving equipment, at the same time employing synchronized scanning at the transmitted scene and at the receiving tube, so that a picture is reproduced for transient visual observation. Figure 12-1 shows a functional diagram of the essential elements in operation between the initial camera where the picture is converted into electric impulses and the final receiver where these electric impulses are reconverted into a picture on a screen.

The cathode-ray tube is the heart of the electronic television system. Figure 12-2 indicates the stages in the processes of television transmission and reception, where the cathode-ray tube is essential. A stream of electrons formed by an electron gun within the cathode-ray tube is readily influenced by either electric fields or magnetic fields. By suitable focusing, this stream of electrons can be brought down to a fine spot which covers substantially one single picture element of the picture to be transmitted or received. Television is best accomplished by breaking a scene down into individual picture elements and employing a systematic scanning process, so that the picture elements are converted into electric signals, each characteristic of the brightness of successive picture elements and succeeding one another in rapid sequence. A picture having thus been analyzed may be sent out on a single radio-frequency carrier as a succession of intelligible electric amplitudes. In the receiver it is necessary to synthesize or reassemble these signals into a replica of the original picture. This is done by means of a cathode-ray tube using a fluorescent screen upon which the pictures are viewed.

In practice, a television system operates in the following manner. The scene to be transmitted may originate either from motion picture film, from a special stage in a studio, or from some direct outdoor event. Figure 12-3 shows studio televising as viewed from the control room. The scene is focused by a suitable lens system onto the mosaic of the television camera tube. This mosaic has many thousand individual islands which are photo-

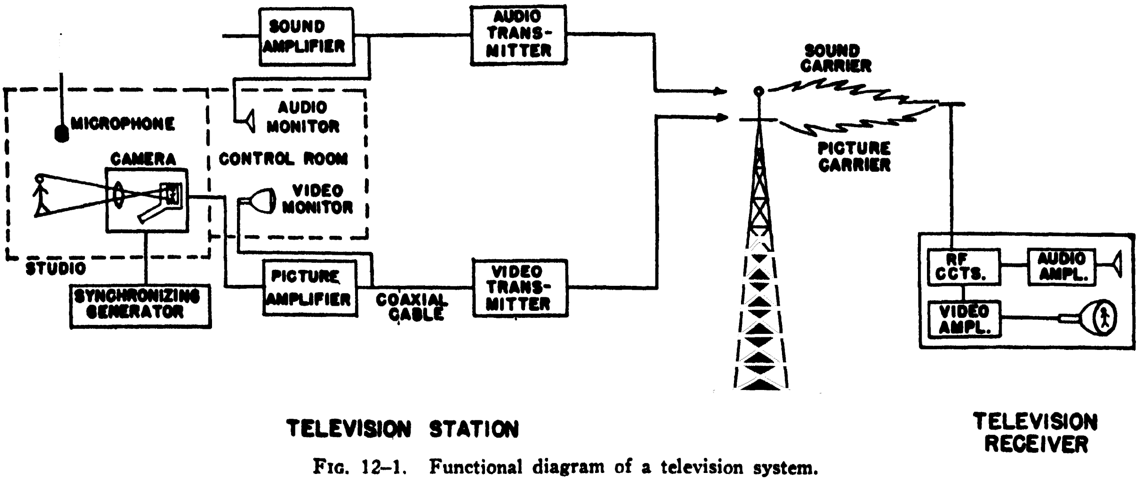

FIG. 12-1. Functional diagram of a television system.

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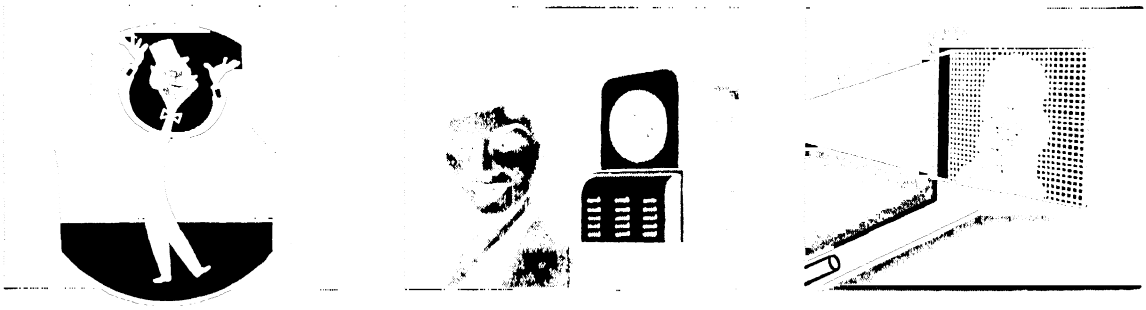
[1] This chapter was prepared by Dr. Thomas T. Goldsmith, Jr., Director of Research, Allen B. Du Mont Laboratories, Inc.

WHAT IS TELEVISION?

Alec Electron is back and this time he has his own over-simplified explanation of this question



Here I am again - Little Alec Electron

I'm the works in Television—and how!

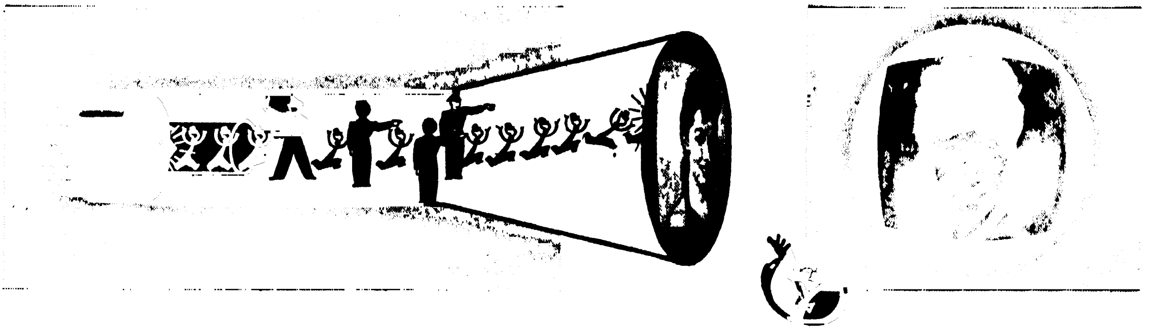
Paulette Goddard* is being televised by a camera which has, instead of film, a vacuum tube with a flat surface of tiny particles of an unusual substance Here we electrons are comparatively free When light hits us, some of us absorb enough energy so that we're able to jump off

When the light of Paulette's image falls on this surface, we jump with joy, and jump right off! It's really the light that makes us leave, and the stronger the light, on each point of the image, the more of us jump from that point Thus we re-create her image in lights

Now, this tube has a squad of Military Police electrons who check up on us They act as a Cathode Ray beam, and with it thirty times each second they scan the whole flat surface left to right, top to bottom, reading the whole picture exactly as you'd read the page of a book.

They send out messages which tell just when each new 'scanning' starts (scientists call it the synchronizing signal) And as they scan the picture they also send to the M P's in your receiving set information as to the number of us jumping from each point

These messages, both starting signals and the number of electrons leaving each point are sent to the television transmitter and pumped into the air as radio waves They are instantly intercepted by your antenna and sent into your receiving set, where the pictures are reproduced.



The radio wave orders are picked up by Grid Sergeants in the Cathode Ray Tube in your receiver This Cathode Ray Tube is the heart of the television set, and was commercially developed by the Allen B DuMont Laboratories When these Sergeants get their signals, we electrons get ordered around As the Sergeants respond to the radio signal they maneuver us to scan the fluorescent screen in perfect coordination with the electron beam in the camera tube As directed, they send exactly the same number of us to each point of the screen in your set, as was on each point of the screen in the television camera. When we hit the screen we produce a point of light in proportion to our number, shading through light and dark areas, the contours of a picture.

That's how we reproduce the same picture in your television set almost at the same instant it is "scanned" in the studio Back in the station those Military Police are sending out thirty complete pictures every second Of course, nobody's eyes work that fast, so the effect you get is of one continuous moving picture—or television!

* *Allen B DuMont Labs., Inc.*

FIG. 12–2. Pictorial explanation of operation of television station.

FIG. 12–3. Television studio and control room.

sensitive. Thus the scene focused on these islands will charge up the individual elements of a mosaic to an extent depending upon the brightness of the individual small picture areas or elements in the scene. A systematic method of electron beam scanning of this mosaic is employed in the camera tube. The beam is made to produce a series of parallel lines going from left to right across the scene at a relatively high speed governed by the horizontal line scanning electric circuits. At the same time a low-frequency or vertical-field scanning circuit causes the beam to move slowly from top to bottom of this scene, thus spreading out the horizontal scanning into a closely woven pattern substantially covering the entire scene.

As the electron stream in the camera tube strikes a given picture element on the mosaic, it releases an electric charge corresponding in strength to the brightness of that portion of the scene. As the electron beam moves on to a new picture element, the released electric energy assumes a new value corresponding to the new picture element brightness. This electric energy is collected by a terminal in the camera tube and is led off to a suitable wide-band video-frequency amplifier.

A synchronizing generator is part of the standard television equipment. It consists of oscillators suitably interlocked so as to produce line-frequency impulses and field-frequency impulses stably related to one another These impulses are used to control the line and field-scanning action on the camera tube. Certain blanking signals are also generated from these same impulses for use in suppressing unwanted signals otherwise generated on the flyback time of the scanning action in the camera tube. These same line- and field-frequency impulses, after suitable shaping, are combined with the video signals to form a composite television signal suitable for transmission either by cable or by radio to remote points.

At the receiver, this composite television signal contains the three basic types of information necessary for synthesis of the television picture. The horizontal line-frequency synchronizing pulses are used to control the line deflection circuits of the receiver. The vertical synchronizing pulses are used to control the field scanning circuits of the receiver. The video signals in the composite television waveform are applied to the intensity modulating electrode of the cathode-ray tube to vary the number of electrons falling on the fluorescent screen so as to produce a replica of the original scene.

One important difference between the electronic requirements of television and of sound broadcasting is that television employs much higher frequencies for its satisfactory transmission than the frequencies usually involved in sound broadcasting. To produce a television picture of high definition, it is necessary to transmit faithfully a very large number of picture elements per picture. In order to prevent serious flicker of the received pictures and to provide a satisfactory illusion of motion, it is necessary that the picture repetition rate be at least of the order of 30 per second. In each television picture there are transmitted between 200,000 and 500,000 picture elements to give adequate resolution. For example, 300,000 picture elements per picture and 30 pictures per second will require transmission of 9,000,000 picture elements per second, not yet correcting for blanking time. With the crude assumption that the resolution might be made up of a checkerboard pattern of successive black then white adjacent areas, a black element and a white element can be said to provide one sine wave cycle of the highest video frequency. Thus our 9,000,000 picture elements may be divided by 2, yielding 4,500,000 cycles per second as the highest video frequency. Even thus, crisp edges are not possible on this checkerboard unless still higher frequencies are used. Of course, much of the detail in the scene will not have this fine resolution and, consequently, the video or picture signal may vary slowly for certain portions of the picture and rapidly for other portions of the picture, resulting in video signals covering a wide frequency range beginning at low frequencies for transmission of the regions of uniform shading and going to high frequencies of the order of several megacycles to reproduce the finest detail. This requirement is, of course, vastly different from the conventional sound broadcasting equipment with its range requirements of, say, 15 cycles per second to 15,000 cycles per second for audio frequencies.

Consequently, in a television system much more care has to be given to wide-band amplifier design in the pick-up equipment and in the station amplifying equipment. Since the modulating frequencies cover an extremely wide band, it is necessary to employ a still higher carrier frequency, at least several times the highest video frequency. The transmitter must be capable of modulation by these wide frequency band signals, so that all of the modulating frequencies are faithfully transmitted. With this wide-band modulation it is generally not possible to obtain as great an efficiency in the transmitter as may be realized in the broadcasting of sound. However, once the general principles of television are understood, the operation and maintenance of television equipment becomes straightforward, even though somewhat more complex.

Sound signals accompany the television pictures. It is the practice to employ two transmitters in a television station, one for the picture and one for the sound. These two transmitters are systematically spaced as to carrier frequency, so that a single receiver may utilize both the picture and the sound. At the receiver a twin superheterodyne circuit is often employed, whereby the one local oscillator beats with the two incoming carrier frequencies, which are thus reduced to intermediate frequencies, each diverted to independent i-f channels, one for the picture and one for the sound.

As a frequency spectrum conservation measure, it is the practice to utilize single sideband transmission and reception for the picture channel. By this scheme, nearly all of the upper frequency picture sideband and only a portion of the lower frequency sideband associated with the picture carrier are radiated. The receiver has circuits which complement this special type of radiation, and the detected picture signals are thus a faithful reproduction of the modulating waveform fed to the transmitter.

The sound equipment in the television studio and control rooms, as well as the sound broadcasting transmitter, is conventional.

In brief, a television system operates by analyzing the original scene in a photoelectric camera tube, amplifying the resulting video signals, transmitting these signals along with synchronizing control signals, and utilizing these composite signals at the receiver to convert the electric signals back into a picture upon a cathode-ray tube.

FIG. 12–4. TABULAR SUMMARY FOR REQUIREMENTS FOR CLASS A TELEVISION STATION

Two studio cameras, with push dollies.
Studio control desk.
Two special film projectors.
Two film pick-up cameras.
Master control board.
Studio lighting and audio equipment.
Field picture pick-up equipment, including two cameras.
Field audio pick-up equipment.
Field relay transmitter.
Relay receiver.
Truck with generators and antenna.
25-kw peak video and 12.5-kw peak audio transmitter with control console.
Suitable antenna for above transmitter.
Soundproofing, electrical wiring and structural alterations for studio, transmitter and control rooms.
Fireproofing of film projection room.
Spares and test equipment.

The tabular summary of requirements for a television station, Figure 12–4, gives an over-all picture of necessary components required for a Class A television station. This tabular summary should be considered as representing the typical requirements for a station, rather than the total necessary requirements.

Now that the general principles of a television system have been briefly described, the several divisions of a television station will be taken up one by one in more detail. In view of the newness of the art, it has been felt worthwhile to provide here a list of terms with definitions, so that the reader may become more familiar with some of the language which has grown up with the television techniques.

12-2. Television definitions

Accelerating Electrode—Otherwise known as Anode No. 2. This electrode serves to increase the kinetic energy of the electron stream by increasing its velocity so that upon impact on the screen a visible radiation will be emitted.

Aspect Ratio—The ratio of picture width to picture height. Usually 4:3.

Astigmatism—Focus condition in which the spot is not round, thus causing different trace widths depending upon the direction of the trace.

Bandwidth—The number of cycles per second required to convey the information being transmitted either visual or aural.

Blacker-than-black—A portion of the television signal devoted to synchronizing. These synchronizing signals are transmitted at a higher power than the blackest part of the picture. This occurs when the spot returns from the far right to begin the next line and from the bottom to the top of the picture.

Black Level—The amplitude of the modulating signal when camera is receiving no light.

Blanking—The process of cutting off the cathode ray during the time it is not forming a part of the picture. This occurs when the spot returns from the far right to begin the next line and from the bottom to the top of the picture to begin the next field.

Blanking Pulse—Pulse produced to "blank out" signal caused by the return sweep of the cathode-ray beam in both the camera tube and the cathode-ray tube.

Brightness Control—A control on the receiver for regulating electron current and thus the over-all brightness of the picture.

Camera Tube—The electron tube used to translate a scene into electrical impulses.

Cathode-ray Tube—An electron tube in which streams of electrons from a cathode are formed into a pencil-like beam and directed by means of electric or magnetic fields over a target, usually a fluorescent screen which glows wherever the beam strikes.

Center Frequency—(as applied to frequency modulation) means the frequency of the carrier wave with no modulation. (With modulation the instantaneous operating frequency swings above and below the center frequency. The operating frequency with no modulation shall be the center frequency within the frequency tolerances.)

Coaxial Cable—A particular type of cable capable of passing a wide range of frequencies without the usual prohibitive losses. Such a cable in its simplest form consists of a hollow metallic conductor with a single wire accurately confined along the center of the hollow conductor.

Contrast—This refers to the ratio of the white to black portions of a picture. Pictures having high contrast have very deep blacks and brilliant whites, while a picture with low contrast has an overall gray appearance.

Contrast Control—A control on the receiver which regulates the video signal strength. This has the effect of changing the ratio of the black and white portions of the picture. It corresponds to the volume control in an aural receiver.

Control Electrode—A metal structure adjacent to the cathode which controls the potential relationship between this electrode, sometimes called the grid, and the cathode. This electrode controls the light intensity of the image on the screen of the tube by controlling the magnitude of the beam current.

D-c Restorer—This circuit regulates the average brightness of the television picture tube to correspond with the average brightness of the scene being transmitted.

D-c Transmission—"D-c transmission" means the transmission of a television signal with the direct current component represented in the picture signal.

Deflection—The lateral movement of the cathode ray beam by electric or magnetic fields.

Deflection Plates—Usually consist of two pairs of parallel plates, the pairs being perpendicular to each other. The electrostatic field existing between each plate pair causes angular displacement of the electron beam.

Delay Screen—A fluorescent screen used in cathode ray tubes, which has the property of phosphorescence. When this material is used, the light intensity of any particular spot dies out gradually after the ray moves to a new position.

Dissector Tube—A dissector tube is a pick-up tube having a continuous photo-cathode on which is formed an electron current density image, the electron optical image of which is moved over a scanning aperture.

Electromagnetic Focusing—A system in which magnetic fields parallel to the streaming motion of the electrons are used to confine the electrons to a narrow beam.

Electron Gun—That part of a cathode-ray tube in which the electrons are emitted and formed into a beam.

Electron Lens—A systematic arrangement of electromagnetic or electrostatic fields, having symmetry about the axis of a cathode-ray tube, as to their radial components, established for the purpose of controlling the divergence and convergence of the electron ray.

Electron Multiplier—An evacuated amplifier tube in which one or more anodes have photoelectric surfaces which are exceedingly active as to secondary emission. The original electron emission is cascaded by the secondary effects.

Electrostatic Focusing—A system in which electric fields are employed to confine the electrons into a thin stream.

Field—This term refers to one set of scanning lines making up a part of the final picture. In present standards, pictures are transmitted in two fields of 262½ lines each, which are interlaced to form 30 complete frames per second.

Field Frequency—This term refers to the repetition rate of the field, which in present systems is 60 per second and is twice the frame frequency.

Fluorescent Screen—A chemical coating on the inside of a cathode-ray tube which emits light at the point where a cathode-ray beam strikes.

Flyback—In scanning, the spot is moved across the screen at a definite rate in one direction for each scanning line. Thereupon, it is necessary to restore it to the start of the next line in a very short interval of time, say three or four millionths of a second. This return time is termed "flyback."

Focus—In a cathode-ray tube this refers to the size of spot of light on the screen. The tube is said to be focused when the spot is smallest. This term also refers to the optical focusing of the camera lenses.

Focusing Electrode—A metal cylinder, otherwise known as Anode No. 1. The electrostatic field produced by this electrode in combination with the control electrode, and the accelerating electrode (see text, p. 447) acts similarly to an optical lens in focusing the electron stream to a small spot on the screen.

Frame—One of a series of complete pictures that are successively viewed so as to simulate moving scenes.

Frame Frequency—Frame frequency is the number of times per second the picture area is completely scanned.

Ghost—A secondary picture formed on a television receiver because the signal from the transmitter reaches the antenna by more than one path. Ghosts are most commonly caused by the radio signal being reflected from objects within approximately one mile of the receiver antenna.

Halation—The ring of illumination which surrounds the point at which the electron beam strikes the fluorescent screen.

Iconoscope—An iconoscope is a pick-up tube in which a high velocity electron beam scans a photoactive mosaic which has electrical storage capability.

Image Dissector—A television camera tube developed by P. T. Farnsworth in which the photoelectrons are moved over a pick-up aperture by deflection circuits.

Intensifier Electrode—Otherwise known as Anode No. 3. Imparts additional kinetic energy to the electron stream after deflection. This post-acceleration results in an increase in light intensity without a large decrease in deflection sensitivity (see text).

Interlaced Scanning—A system whereby the odd numbered lines and the even numbered lines of a picture are sent as two consecutive separate fields and superimposed to create one frame or complete picture.

Ion Spot—A discoloration on the center of the screen of a cathode-ray tube caused by heavy negative ions striking it.

Keystone Effect—A distorted field or background noticed in some cases with television pictures, where the opposite edges are not parallel.

Kinescope—A name sometimes applied to a cathode-ray tube used as a picture tube.

Line—The path traced by the moving electron spot. The intensity of the spot along this path is altered to create that portion of the picture. In some present systems 525 lines make up the complete picture.

Line Frequency—The number of lines scanned each second. In any system it is equal to the number of scanning lines per frame, multiplied by the framing frequency.

Lumen—A lumen is a unit of light flux. A foot-candle is equal to illumination that falls on a screen that is placed one foot away from a standard candlepower. One foot-candle is equal to one lumen per square foot of surface.

Modulation Grid—An electrode interposed between the cathode and focusing electrodes in a cathode-ray tube to control the amount of emission and thereby the brilliance of the spot. This controlling effect is produced by altering the voltage of this grid with respect to the cathode.

Monochrome Transmission—means the transmission of television signals which can be reproduced in gradations of a single color only.

Monoscope—A monoscope is a pick-up tube in which an electron beam scans a target, parts of which have different secondary emission characteristics.

Mosaic—The screen used in an Iconoscope so called due to its similarity to that form of art wherein a great many bits of colored tile are combined so as to form a picture.

Multipath Transmission—The condition in which the radio signal from the transmitter travels by more than one route to a receiver antenna usually because of reflections from obstacles. This condition usually results in ghost pictures.

Negative Ghosts—are ghost pictures which appear on the screen with an intensity inversion.

Negative Transmission—means that a decrease in initial light intensity causes an increase in the transmitted power.

Orthicon—An orthicon is a pick-up tube in which a low velocity electron beam scans a photoactive mosaic which has electrical storage capability.

Oscilloscope Tube—An oscilloscope tube is a cathode-ray tube on which the visible pattern is the graphical representation of electrical impulses applied to the deflecting system.

Pedestal—A portion of the television video signal used to blank out the cathode-ray beam as it flies back from the right edge of the picture to the left.

Phosphor—A phosphor is a substance capable of luminescence.

Photoelectric Emission—The phenomenon of electrons being emitted from certain materials when they are exposed to light.

Pick-up Tube—A pick-up tube is an electron beam tube in which an image of electrical current or charge density is formed and scanned in a predetermined sequence to provide an electrical signal.

Picture Element—A small section of a given scene as reproduced by the cathode ray spot at any instant.

Picture Noise—Interference signals causing spots of light and other irregular patterns on the received picture. Sometimes called "grass."

Positive Transmission—A television system in which maximum radiated power from the transmitter corresponds to maximum white area in the picture. Not used in the United States.

Progressive scanning—means a scanning process in which scanning lines trace one dimension substantially parallel to a side of a frame and in which successively traced lines are adjacent.

Raster—The raster is a predetermined pattern of lines or traces which provides substantially uniform coverage of a target area.

Return Trace—The lines on the cathode-ray screen formed as the cathode-ray beam moves back to its starting position for line or field.

Saw-tooth—A voltage or current whose variation with time follows a saw-tooth outline.

Scanning—means the process of analyzing successively, according to a predetermined method, the light values of picture elements constituting the total picture area.

Scanning Line—means a single continuous narrow strip containing highlights, shadows, and halftones which is determined by the process of scanning.

Shading—The process of correcting by compensating variable potentials the light distribution in the image produced by the television camera.

Spot—The light produced by the impact of the slender beam of electrons on the fluorescent screen.

Sweep—The uniform motion of the electron beam across the face of the cathode-ray tube.

Synchronization—The process of keeping the moving beam of electrons at the picture tube in the exact relative position with the scanning process at the transmitter.

Television—Television is the electrical transmission and reception of transient visual images.

Television Camera Tube—A cathode-ray tube used to convert the light and shade portions of a scene into electrical signals.

Television Picture Tube—A cathode-ray tube in which a picture being transmitted is recreated by a moving beam of electrons.

Test Pattern—A drawing containing a group of lines and circles, etc., transmitted for receiver and transmitter test purposes.

Vestigial Side Band Transmission—A method of suppressing part of one side band to limit bandwidth requirements.

Video—The portion of the television signal which contains the picture information.

Video Frequency—The frequency of the signal voltage containing the picture information which arises from the television scanning process.

View Finder—A term applied to an attachment to a television camera to enable the cameraman to observe the area within view of the camera. View finders may be optical in nature or may consist of a cathode-ray tube monitor.

Viewing Screen—A viewing screen of a cathode-ray tube is the medium which converts the energy of the beam electrons into visible radiation.

Yoke—A set of coils used around the neck of a cathode-ray tube to produce horizontal and vertical deflection of the electron beam.

12-3. Television Transmission Standards (made effective December 19, 1945 by F.C.C. for commercial black-and-white television broadcasting)—

1. The width of the television broadcast channel shall be 6 mc per second.

2. The visual carrier shall be located 4.5 mc lower in frequency than the aural center frequency.

3. The aural center frequency shall be located 0.25 mc lower than the upper frequency limit of the channel.

4. The visual transmission amplitude characteristic shall be as shown in Figure 12-5.

5. The number of scanning lines per frame period shall be 525, interlaced two to one.

6. The frame frequency shall be 30 per second and the field frequency shall be 60 per second.

7. The aspect ratio of the transmitted television picture shall be 4 units horizontally to 3 units vertically.

8. During active scanning intervals, the scene shall be scanned from left to right horizontally and from top to bottom vertically, at uniform velocities.

9. A carrier shall be modulated within a single television channel for both picture and synchronizing signals, the two signals comprising different modulation ranges in amplitude. (See Figures 12-5 and 12-6.)

10. A decrease in initial light intensity shall cause an increase in radiated power (negative transmission).

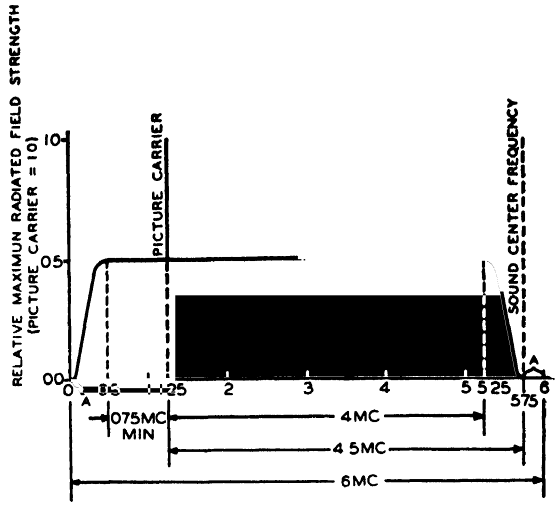


FIG. 12-5. Idealized picture transmission amplitude characteristic.

11. The black level shall be represented by a definite carrier level, independent of light and shade in the picture.

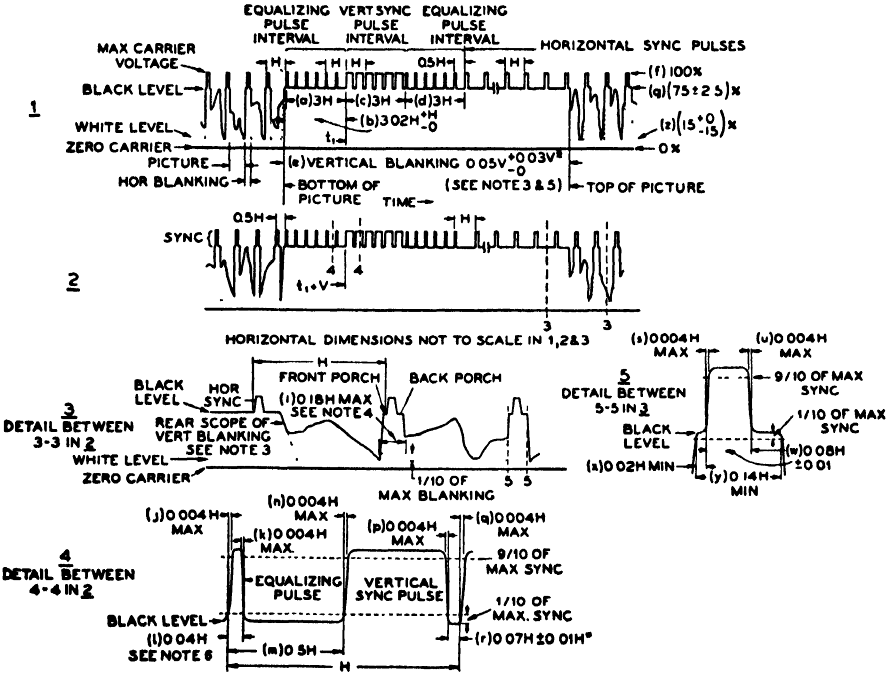
12. The pedestal level (normal black level) shall be transmitted at 75 percent (with a tolerance of plus or minus 2.5 percent) of the peak carrier amplitude.

13. The maximum white level shall be 15 percent or less of the peak carrier amplitude.

14. The signals radiated shall have horizontal polarization.

15. A radiated power of the aural transmitter not less than 50 percent or more than 150 percent of the peak radiated power of the video transmitter shall be employed.

16.[2] *Variation of output.* The peak-to-peak variation of transmitter output within one frame of video signal due to all causes, including hum, noise,



Note

1—H = time from start of one line to start of next line.

2—V = time from start of one field to start of next field.

3—Leading and trailing edges of vertical blanking should be complete in less than 0.1H.

4—Leading and trailing slopes of horizontal blanking must be steep enough to preserve min. and max. values of (x + y) and (L) under all conditions of picture content.

*5—Dimensions marked with an asterisk indicate that tolerances given are permitted only for long time variations, and not for successive cycles.

6—Equalizing pulse area shall be between 0.45 and 0.5 of the area of a horizontal sync. pulse.

7—Refer to text for further explanations and tolerances.

FIG. 12-6. Television synchronizing waveform.

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[2] These items are subject to change but are considered the best practice under the present state of the art. They will not be enforced pending a further determination thereof.

FREQUENCIES FOR COMMERCIAL TELEVISION CHANNELS
(as of Jan. 1, 1950)

Channel Number	Megacycles	Channel Number	Megacycles
2	54–60	7	174–180
3	60–66	8	180–186
4	66–72	9	186–192
5	76–82	10	192–198
6	82–88	11	198–204
		12	204–210
		13	210–216

and low-frequency response, measured at both synchronizing peak and pedestal level, shall not exceed 5 percent of the average synchronizing peak signal amplitude.

17.[2] *Black level.* The black level should be made as nearly equal to the pedestal level as the state of the art will permit. If they are made essentially equal, satisfactory operation will result and improved techniques will later lead to the establishment of the tolerance if necessary.

18.[2] *Brightness characteristics.* The transmitter output shall vary in substantially inverse logarithmic relation to the brightness of the subject. No tolerances are set at this time.

12–4. Cathode-ray Tubes—The cathode-ray tube is a device employing a focused beam of electrons which may be deflected over a surface. The target may be either fluorescent in nature to produce light or else photosensitive in nature for the purpose of converting light into electric signals. The tubes employ electrostatic or magnetic deflection of the focused beam of electrons. The electrostatic deflection type of cathode-ray tube is more suited to uses where a wide frequency range of deflecting signals is to be encountered. However, on the television pick-up camera tubes and in the television picture receiving cathode-ray tubes, the deflection signals are predetermined and can have a limited frequency range. For example, a vertical deflection sawtooth waveform at 60 cycles per second for field frequency and a horizontal deflection sawtooth waveform of 15,750 cycles per second for line frequency may be employed. For these specific waveforms it is possible to design economical magnetic deflecting coils for both camera tube and viewing tube. In magnetic deflection tubes it is necessary to provide the required number of ampere-turns of the proper frequency response for the deflecting coils. In electrostatic deflection tubes the required voltage with satisfactory frequency response must be provided.

Figure 12–7 shows a typical electrostatic-deflection cathode-ray tube. A magnetic-deflection cathode-ray tube is similar in principle to that in Figure 12–7, except that the deflection plates are omitted inside the tube. Instead two pairs of coils comprise a deflecting yoke which may be placed around the neck of the tube at approximately the same position illustrated for the deflection plates. Generally, the cathode-ray tube neck will have, in this case, a smaller diameter, so that the coil may have a small internal diameter, thus yielding a high deflection sensitivity.

In some types of magnetic-deflection tubes the electron gun within the cathode-ray tube is further simplified. Instead of the focusing electrode (11) of the tube of Figure 12–7, a simple cathode, control grid and possibly low-voltage screen grid comprise the entire electron gun within the tube. The wall coating of the bulb then serves as the high-voltage anode for the electron beam. Now a solenoid of many ampere-turns is placed around the neck, the axis of the solenoid being concentric with the axis of the tube. This focusing coil provides a magnetic field capable of bringing the electron stream to a sharp focus on the fluorescent screen. In some applications this process has advantages over the use of electrostatic-focus, electrostatic-deflection tubes. For example, the extreme simplicity of the cathode-ray tube is economical for replacement considerations. However, the cost of the focusing

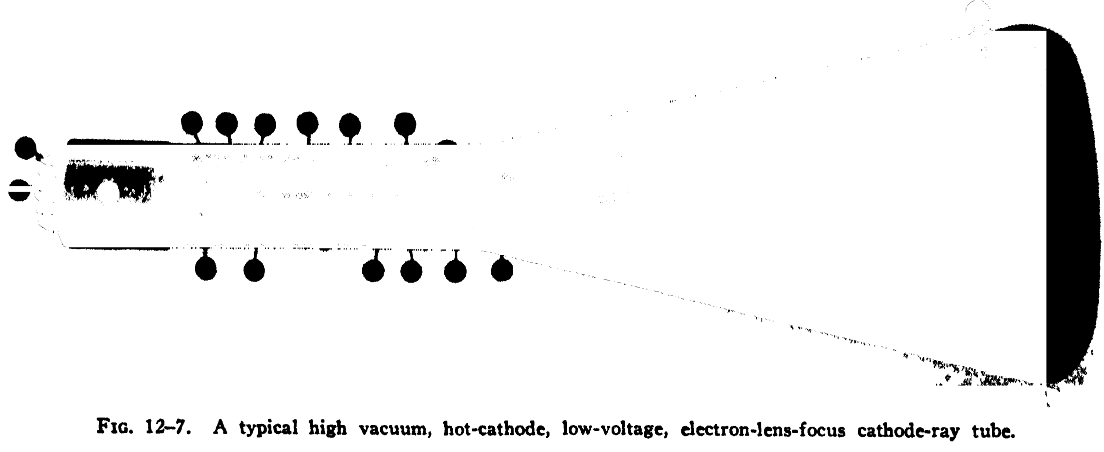

FIG. 12–7. A typical high vacuum, hot-cathode, low-voltage, electron-lens-focus cathode-ray tube.

and deflecting assemblies is greater in the initial equipment than would be the cost of the simple additional parts within the cathode-ray tube. For some purposes the magnetic-focus, magnetic-deflection type cathode-ray tube yields finer focus with high brightness. Where relatively fixed deflection signals are employed, this magnetic tube is often used.

The electrostatic-deflection type of tube, however, is employed almost exclusively where the actual television waveforms must be analyzed in detail.

Cathode-ray tubes operate with accelerating voltages of 1000 volts for smaller tubes. These tubes are generally employed for observing patterns of limited writing length, and where the patterns usually are recurrent. On larger tubes, used for picture reproduction, the accelerating voltage may be as high as 20,000 volts, yielding increased brightness and generally better focus. The electron beam current may vary anywhere from 5 microamperes to several hundred microamperes, depending upon the type of tube.

The cathode-ray tube screen is a combination of chemicals blended to produce white light for television reception purposes. This blend usually consists of a blue component and a yellow component.

For waveform observation, a willemite screen is often used, which produces green light. The luminous efficiency of the green phosphor accounts for its widespread use for oscillograph purposes. Where photographic records are desired, a fluorescent screen producing blue light is best.

12–4a. The Modern Cathode-ray Tube—An outline drawing of a modern high-vacuum cathode-ray tube is shown in Figure 12–7. The parts shown are as follows:

1. Base pins.
2. Alignment key.
3. Base collar.
4. Stem.
5. Getter.
6. Press.
7. Heater leads (heater inserted inside the cathode tubing).
8. Cathode support collar (cathode inserted inside the grid tubing).
9. Ceramic supports (two supports diametrically opposed).
10. Control electrode.
11. Focusing electrode.
12. Support collar.
13. Accelerating electrode.
14. Mount supports.
15. Mica deflection plate support rings.
16. Deflection plate pair D_3–D_4
17. Deflection plate pair D_1–D_2.
18. Spring contact (makes contact with static shield.
19. Static shield.
20. Glass envelope.
21. Electron beam.
22. Intensifier electrode.
23. Intensifier terminal.
24. Fluorescent screen material.
25. Pattern traced by beam.

A heater element (7) mounted within a cathode sleeve (8) operates to heat the oxide coating on the end of this sleeve and causes electron emission. The electric field produced by the control electrode or grid (10) and the focusing electrode (11) acts to draw the electrons emitted from the cathode into a narrow beam having a small minimum cross section in the vicinity of the grid.

From this point the electron beam diverges until it passes through the region between the focusing electrode (11) and the accelerating electrode (13) where the electric field set up by these electrodes causes the beam to converge so that it reaches the fluorescent screen (24) in a small spot. This action is analogous to the action of optical lenses on light, and it may be said that the minimum beam cross section in the vicinity of the grid is focused onto the screen by the electron lens formed by the field between the focusing electrode and the accelerating electrode.

The control electrode is ordinarily operated at a negative potential with respect to the cathode, and the beam current (and therefore the brightness of the spot) is varied by varying this bias potential. This potential difference is of the order of 100 volts maximum. The focusing electrode usually operates at a lower voltage than the accelerating electrode, and it is by variation of this focusing electrode voltage, in the vicinity of 500 volts for 2000 volts accelerating potential, that the spot is properly focused on the screen. The entire beam-forming structure is known as the "electron gun."

After leaving the gun the electron beam passes between the plates of deflection plate pair 16 and then between the plates of pair 17. A potential difference applied between the plates of pair 16 produces an electric field which deflects the electron beam in a direction perpendicular to the plane of those plates. Similarly a potential applied between the plates of pair 17 results in deflection of the beam in a direction perpendicular to the direction of deflection produced by plate pair 16. Thus it is possible to control the position of the spot on the screen by two potentials applied to the two sets of deflection plates.

It will be noted that in this cathode-ray tube focusing and deflection of the beam are both accomplished by electrostatic fields. It is also possible to use electromagnetic fields for either focusing or deflection, or both.

The intensifier electrode (22) is operated at a higher voltage than the accelerating electrode. This intensifier electrode serves to accelerate the

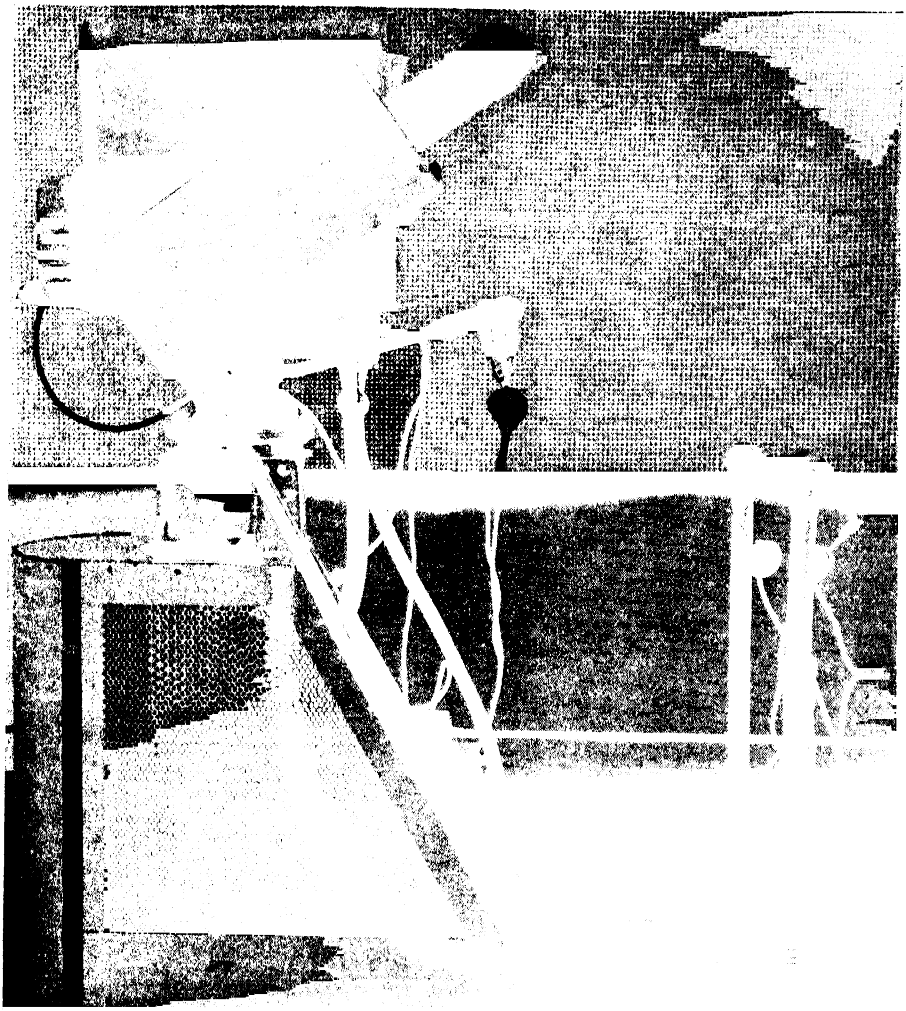

FIG. 12–8. Television studio camera of iconoscope type.

beam further subsequent to deflection. The sensitivity of the beam to electrostatic deflection varies inversely with the potential applied to the accelerating electrode, which potential, measured from cathode, determines the velocity of electrons in the deflection plate region. However, the brilliance of the trace caused by the electron beam increases with increase in accelerating potential. A compromise therefore must be made between brilliance and deflection sensitivity. With the intensifier-type cathode-ray tube, the necessity for compromise is greatly reduced, since the beam may be deflected at a low accelerating electrode potential and then further accelerated after deflection by a higher potential applied to the intensifier electrode.

12–5. Television Camera—The television camera consists of the camera tube, the lens, and the associated electrical circuits and power supplies. Figure 12–8 illustrates a studio camera with its movable dolly and intercommunicating phone system. A lens of aperture *f*/3.5 or larger focuses the scene onto the photoelectric target of the picture tube. Provision is usually made for the rapid changing of the lenses using wide-angle, long shot or telephoto lenses, depending upon the type of scene. General studio shots use a wide-angle lens to televise groups of persons. Longer focal length lenses reduce the relative field of view. In some iconoscope tubes the picture mosaic is approximately 3¼ inches by 4⅜ inches and for this size of mosaic a set of three lenses having focal lengths of 8 inches, 12 inches, and 16 inches respectively will satisfy most needs. On certain pick-up tubes having smaller mosaics the lenses may have shorter focal lengths, thus making it simpler to get a large effective aperture. The requirement of brightness levels of approximately 20-foot candles in the highlights on the photosurface of certain pick-up tubes necessitates the large aperture lenses, and consequently depth of focus is a rather serious problem in television. On outdoor pick-ups in sunlight it is often possible to stop the lens down to a point where depth of focus is excellent.

Figure 12-9 illustrates a camera assembly with the camera cover removed, showing a camera tube of the iconoscope type. The tube has a curved polished window, allowing the scene to be projected onto the photosurface, which is in the vacuum. A side arm carries the electron gun which directs a beam of electrons onto the photosurface. The deflecting yoke around this side arm provides two magnetic fields at right angles to one another, one producing horizontal line scanning, say, at 15,750 lines per second and the other producing vertical field scanning, say, at 60 fields per second. Figure 12-9 shows the iconoscope. Since the neck of the tube is at an angle with respect to the target, a scanning pattern, which on a conventional magnetic-deflection cathode-ray tube would appear as a rectangle, will produce on the tilted target of the iconoscope a pattern having the shape of a keystone. However, in practice the horizontal scanning amplitude is modulated by the vertical sawtooth waveform so as to offset this keystoning, thus producing electronic scanning which is rectangular upon the mosaic. An aspect ratio of three units of picture height to four units of picture width is customary in television.

The photoelectric mosaic plate consists of many thousands of tiny isolated elements, thus allowing the picture to be analyzed into a fineness of detail limited only by the size of the individual islands and by the size of the scanning electron stream. The islands are deposited on a thin sheet of mica, the back surface of which has a continuous metallic coating. Thus each island is capacitively coupled to the continuous metallic coating which serves as the signal electrode. When a scene is focused on the mosaic, the islands emit photoelectrons and charge up an amount proportional to the brightness of the picture elements. As the line scanning electron stream comes along, the electrons having a velocity generated by approximately 1000 volts of energy strike these islands and discharge them to

Fig. 12-9. Studio camera with cover removed.

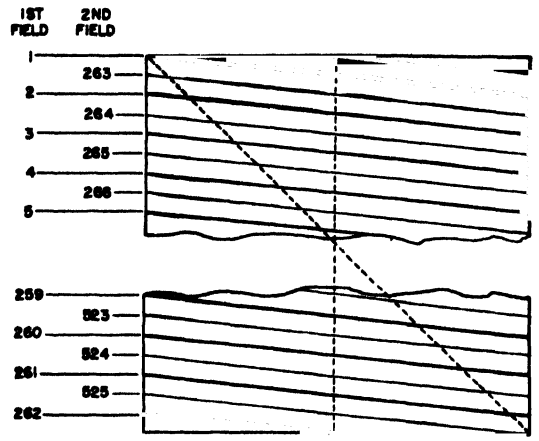

Fig. 12–10. Diagram of interlace scanning.

an equilibrium voltage. The amount of discharge is proportional to the accumulated charge stored up since the previous electron scan. The act of discharging of the islands conveys a capacitively coupled signal to the continuous metallic back plate. In this way the scanning beam produces the series of electrical signals from the respective islands of the mosaic, and the one collecting electrode serves to lead these signals in orderly succession to the video amplifier. Figure 12–10 shows the scanning sequence and indicates how interlace is obtained.

The television camera delivers a signal of the order of 1 millivolt from this terminal; the frequency range of this signal may vary from 30 cycles per second components to as high as several million cycles per second components.

Protective circuits are provided in the television camera. In case the deflection circuits should fail, the electron beam would fall on a small region continuously. As a result, the caesium-silver surface may be evaporated, causing a permanent flaw on the mosaic. Consequently, to prevent danger of burning, the deflection circuits producing the sawtooth waveforms of current driven through the horizontal deflecting coil and vertical deflecting coil are provided with relays which operate only when sufficient deflection amplitude is being delivered to the cathode-ray tube. When these relays are activated by the presence of the deflecting signals, they close suitable circuits to activate the control grid of the camera tube so that a beam is formed. If either sweep fails, the relays open and bias the tube beyond cutoff. The sawtooth oscillators in the television camera are controlled by signals fed from the synchronizing generator which will be discussed later.

RCA IMAGE ORTHICON TUBE

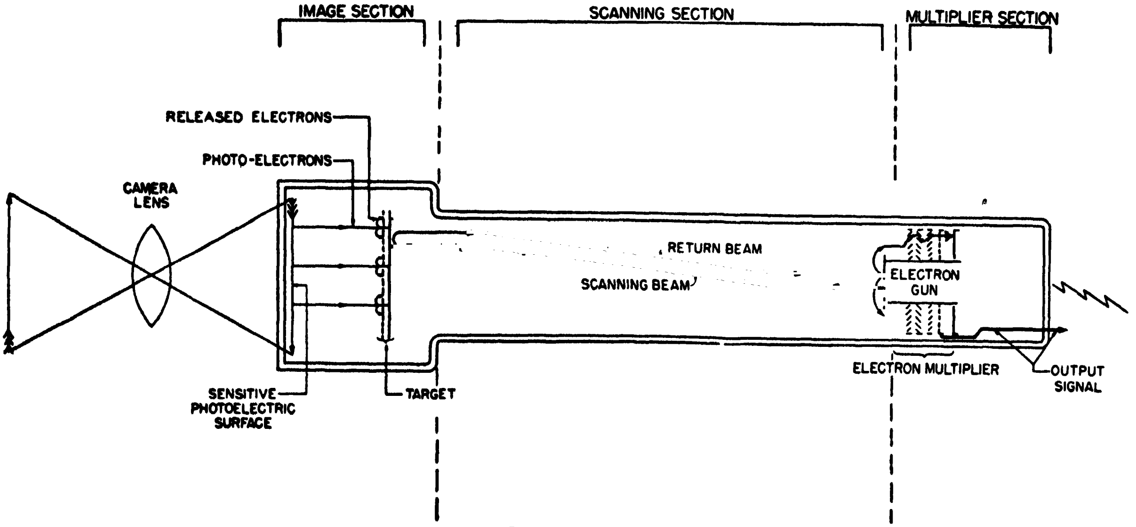

Fig. 12–11.

This simplified functional drawing of the new RCA image orthicon, an ultrasensitive television camera pick-up tube, shows how the tube's response to the light of a single candle, or even a match, is built up to provide a signal which can reproduce images on home receiver screens. A light image from the subject (arrow at extreme left) is picked up by the camera lens and focused on the light-sensitive face of the tube, releasing electrons from each of thousands of tiny cells in proportion to the intensity of the light striking it. These electrons are directed on parallel courses from the back of the tube-face to the target, from which each striking electron liberates several more, leaving a pattern of proportionate positive charges on the front of the target. When the back of the target is scanned by the beam from the electron gun in the base of the tube, enough electrons are deposited at each point to neutralize the positive charges, the rest of the beam returning, as indicated, to a series of "electron multiplier" stages or dynodes surrounding the electron gun. After the returning "signal" beam has been multiplied many times, the signal is carried out of the tube to the television broadcast transmitter. (Courtesy RCA.)

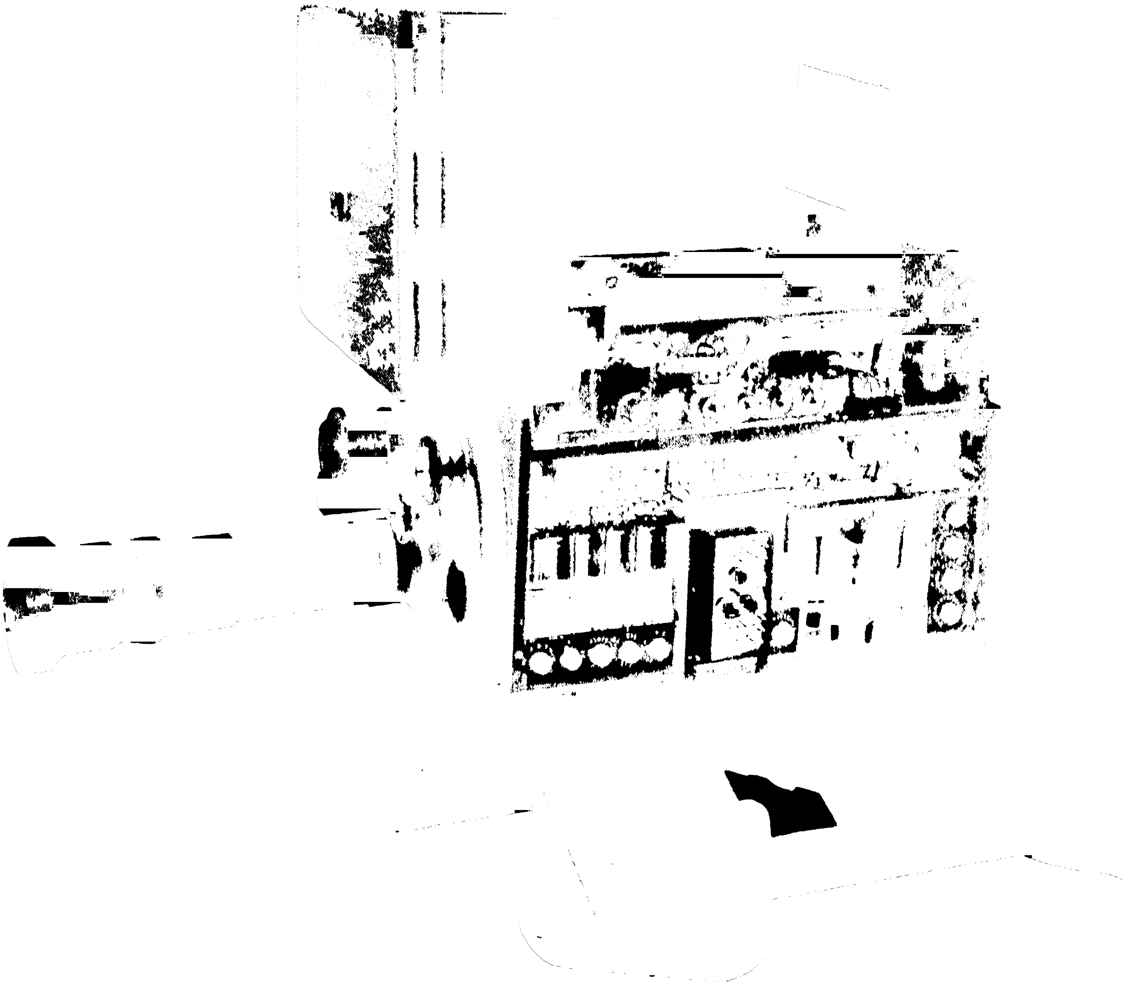

FIG. 12-12. Image orthicon camera head and view finder with cover removed. (Courtesy DuMont.)

The description of a television camera tube thus far is mainly applicable to the iconoscope which is now largely limited to motion picture work. Here both the scene to be transmitted and the electron stream are projected onto the same side of the photosensitive surface. Since the electron stream has an accelerating voltage of approximately 1000 volts, considerable energy is present in the beam and much of the performance of the iconoscope is dependent upon secondary emission in charging and discharging the islands of the mosaic.

Another type of television camera tube, commonly called orthicon, employs a different type of mosaic and uses a lower-voltage electron beam. In the orthicon the scene is focused onto one side of the mosaic plate, while the electron stream scans the other side of the plate. Thus both the picture and the electron stream may strike the mosaic perpendicularly, eliminating the need for keystone correction. With the lower-velocity electron stream of the orthicon, the effect of secondary emission is not as marked, and spurious signals are not so pronounced. The orthicon mosaic is generally smaller in area, thus allowing more efficient lenses. The inherent photosensitivity of the orthicon is better than that of the iconoscope, and the orthicon will work more acceptably under adverse lighting conditions.

12-5a. Image Orthicon Camera—The image orthicon camera using the image orthicon pick-up tube, Figure 12-11, eliminates many of the difficulties encountered in the iconoscope. This more sensitive camera may be used for indoor or outdoor, studio or field programing. With it, scenes may be televised under light levels as low as 3 foot-candles illumination; however, light levels of approximately 30 foot-candles provide results of broadcast quality.

The camera consists of the pick-up head containing the image orthicon tube, electronic view finder, and associated manual controls. The electronic view finder, connected electronically to the pick-up head contains a viewing tube which enables the operator to view the exact scene which is being picked up by the image orthicon tube. Figure 12–12 shows the camera head and view finder with cover removed.

The image orthicon tube [8] is about 100 times more sensitive than the ordinary television pick-up tube. It is about 15 inches long over-all and 3 inches in diameter at its head end. Immediately inside the glass envelope is located a photosensitive emitting surface deposited on a thin glass plate. Light from the televised object is focused on this surface by means of an ordinary camera lens. The photoelectric surface emits electrons when light impinges on it and, by means of a 300-volt potential on a grid behind the face, these electrons are attracted to a target consisting of another non-conducting plate about an inch and a half behind the photoelectric surface. An electromagnetic field keeps the electrons on parallel courses.

When the accelerated photo electrons strike the target they cause the emission of a greater quantity of secondary electrons. There remains a pattern of positive charges on the target due to the deficiency of negative electrons. This pattern corresponds to the pattern of light from the scene.

At the rear end of the tube there is an electron gun which produces a beam of electrons exactly like a cathode-ray tube gun. By means of a deflection system the beam of electrons is caused to sweep back and forth over the rear of the target. As explained above, this target has positive charges on its surface, whose distribution and intensity correspond to the pattern of the picture being televised.

The electron beam has only sufficient velocity to approach the target and then turn around and come back to the attracting positive accelerating plate of the electron gun. However, when the scanning beam moves over a portion of the target containing a positive charge, the additional attraction of the target for the electron beam is sufficient to cause the beam to deposit a few electrons to neutralize this positive charge. The current returning to the accelerating plate of the electron gun then is modulated by the positive charge intensity of the target.

This modulated returning beam strikes the forward surface of the electron gun and causes the emission of secondary electrons which are attracted and accelerated by plates of an electron multiplier. The positive potential from plate to plate is 100 volts and as the electrons strike they cause the emission of a substantially greater number of secondary electrons. When the stream of electrons is finally drawn off on the surface from which the output signal is taken, it has been amplified very substantially.

In order to prevent the electrons from passing through the holes in the electron multiplier without hitting the plates, the holes are cut at an angle in the form of louvres.

As can be seen from the description, this tube is a delicately adjusted mechanism. Not only must the electron beam be of exactly the right strength, but the material from which the target is made must be such as to permit the positive charges to migrate from the front where they are created to the rear where they are scanned. The conductivity must not be so great, however, as to permit the charges to drift around on the surface, thus spoiling the image.

12–5b. The Image Dissector—The third type of television camera tube in common use is called the "image dissector." In such a tube the scene is focused upon a continuous photosensitive surface, and the resulting photo emission is focused as a pattern by suitable focusing fields and accelerated toward a small collecting aperture. Then the whole photoelectric pattern of streaming electrons is deflected in a scanning process, so that individual areas of the picture are successively brought to impinge upon the tiny aperture. The electron stream thus collected is amplified by several stages of electron multipliers using secondary emission. These signals may then be utilized by the video amplifier.

It is common practice to use the iconoscope type of tube with its storage principle for video pick-up and for conversion of motion pictures to television signals. The orthicon tube is more suited to field pick-up equipment in the presence of adverse lighting and is extensively used for color television experimentation, where the sensitivity must be high and where the full storage characteristics of the orthicon are an advantage. The dissector tube proves exceptionally adapted for motion picture conversion to television using continuous film motion.

The camera operator in a studio must pay particular attention to the composition of his scenes in accordance with instruction received by the intercommunicating phone system from the program director. It is his duty to maintain focus by adjusting the lenses and to maintain position and direction of his camera. He is assisted in such operations by the viewfinder associated with the camera. This viewfinder may take the form of a double optical system which shows on a ground glass plate the same scene as the camera observes on its mosaic. In this case the ground glass plate may actually show a little larger area with ruled lines to identify the area being transmitted. However, the electronic viewfinder frequently used consists of a small television picture tube mounted with the camera. The camera operator can thus see the actual picture being produced by his camera and can complete his optical focus and composition of the picture from this study. This electronic viewfinder employs a cathode-ray tube operating at several thousand volts and is substantially a small television receiver. The associated power supplies for the camera and the viewfinder may be located on the lower portion of the camera dolly. The camera is connected with the other control equipment by means of a multiple cable containing several coaxial cables for transmitting the video frequencies, the shading signals, the scanning wave forms, the communicating signals and the remotely generated power requirements.

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[8] The material on the image orthicon tube, supplied by courtesy of Electronic Industries and Radio Corp. of America, appeared under the title "High Sensitivity Pickup" in the December, 1945 issue of *Electronic Industries.*

12-5c. The Flying Spot Scanner—With the development of short persistence phosphors the return to flying spot scanners as suitable high definition signal sources became feasible. The similarity to the early mechanical scanners is quite evident.

A complete electronic scanner requires a standard sync generator, a sweep unit for deflecting the electronic beam of a cathode-ray tube with a short persistence phosphor (i.e., ZnO with a suitable activator), optical means for imaging this raster on variable density or opaque subject matter, a multiplier type photocell to collect either the transmitted or reflected light and represent the variable density or variable reflection as an instantaneous voltage variation with time, and suitable mixing circuits to provide composite video output. The raster traced out on the short persistence screen results in a moving light source. This is the basis of the whole operation. Since the decay time of the moving point source of light is relatively long compared to the period of the highest frequency components desired in the video signal, special peaking circuits must be utilized. The multiplier type photocell produces a high level output signal with a good signal-to-noise ratio. To achieve the resolution required of the final video signal the low frequency components of the output must be attenuated considerably to bring up the high frequency components. This may be accomplished with selective amplifiers or with R–C or R–L networks.

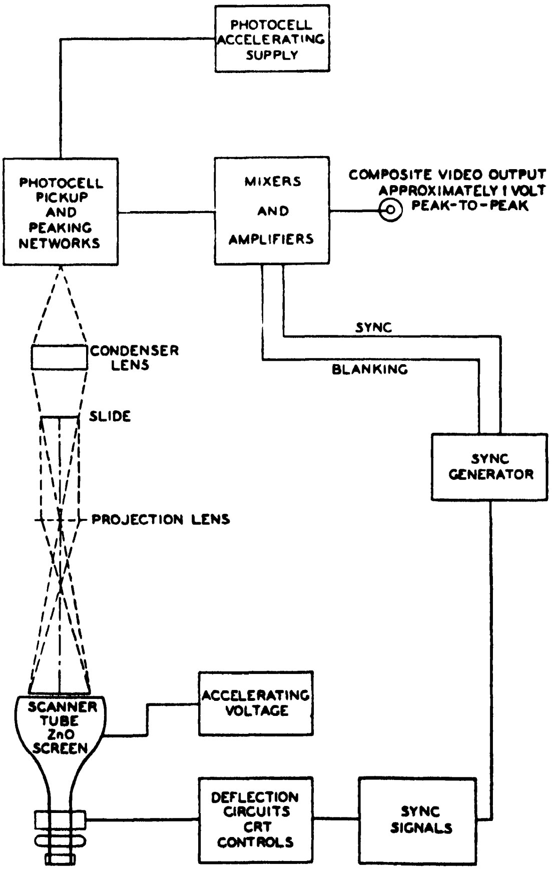
PHOTOCELL ACCELERATING SUPPLY
PHOTOCELL PICKUP AND PEAKING NETWORKS
MIXERS AND AMPLIFIERS
COMPOSITE VIDEO OUTPUT APPROXIMATELY 1 VOLT PEAK-TO-PEAK
SYNC
BLANKING
CONDENSER LENS
SLIDE
SYNC GENERATOR
PROJECTION LENS
SCANNER TUBE ZnO SCREEN
ACCELERATING VOLTAGE
DEFLECTION CIRCUITS CRT CONTROLS
SYNC SIGNALS

Fig. 12–13. Slide scanner using flying spot scanner cathode-ray tube.

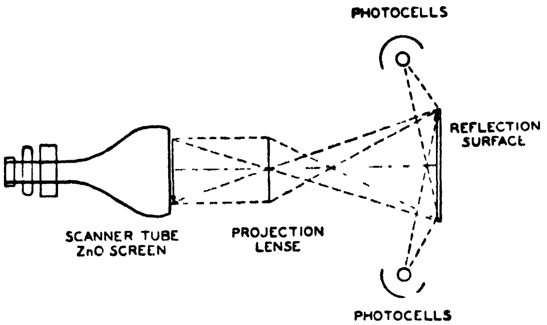

Fig. 12–14. Optics of reflection scanner.

For slide reproduction the raster traced out on the cathode-ray tube is imaged optically on the slide to be reproduced. Condenser lenses are used past this focal plane to collect the maximum light energy passing through the slide, and converge this energy to the aperture dimensions of the multiplier photocell.

When used to reproduce opaque images, a number of photocells in parallel are placed around the object on which the raster from the cathode-ray tube is imaged. The efficiency of this pick-up can be improved by using condenser lenses. A block diagram of a typical slide scanner is shown in Figure 12–13, and the optics of a typical reflection scanner are sketched in Figure 12–14. The final resolution achieved with the flying spot scanner is determined by the beam spot size in the cathode-ray tube, the operating temperature of the short persistence phosphor, the optical focus, the electron beam focus and the peaking circuits used to compensate for the relatively long decay time of the phosphor. The results obtained with this signal source to date have been excellent. It is possible to obtain 500-line resolution with very high signal-to-noise ratio and none of the shading difficulties encountered with the iconoscope or image orthicon pick-ups.

12-6. Video Amplifiers—Since television signals cover a very wide frequency range, they place a rather strict requirement upon the amplifier circuits. The amplifier must provide flat frequency response from a frequency of 30 cycles per second to 5 mc per second. It is, therefore, common prac-

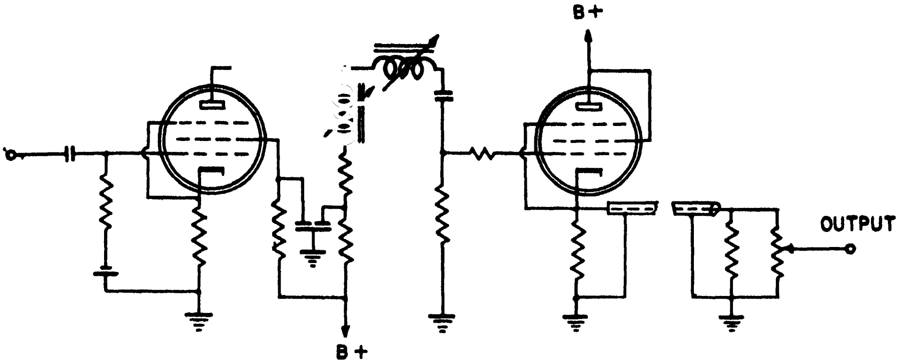

FIG. 12–15. Video amplifier and cathode follower stage as used in line amplifiers to drive a coaxial cable.

tice to utilize resistance-coupled amplifiers employing inductive peaking to maintain the high-frequency response at a suitable value. The distributed capacitance and the grid capacitance of the tube become serious at the upper end of this frequency range and consequently the impedances of the plate load are generally low with values of the order of 1000 ohms or less. The signal level delivered by the camera tube is of the order of 1 millivolt for average signal brightnesses, and it is desirable that the camera be capable of delivering the low-level signals essentially free from noise. The signals must remain therefore noise-free from the order of one-tenth of a mv input and upward. This requirement necessitates extreme care in the design of the early stages of the video amplifier. Choice of good quality resistors is necessary to prevent resistor noise in the early stages. With such extreme sensitivity, the presence of tubes having microphonic characteristics is serious. The early stages of the video amplifier are generally shock-mounted.

The large size of the mosaic plate produces considerable capacitance at the input circuit. It is customary to connect the camera tube terminal to the grid of the first vacuum tube stage, which is a cathode-loaded impedance-matching tube. In this type of circuit the signals are applied to the grid of a tube and the cathode has the load resistor connected in its circuit. In this way the output signals are taken from the cathode of this first tube and there is no actual voltage gain. However, with the relatively low impedance in the cathode circuit the signals are converted from a high-impedance circuit on the camera tube terminal to the low impedance of a cathode circuit. A regenerative action is employed in this cathode circuit whereby the outside shield of the camera tube is connected to this cathode. In this way the capacitance between the mosaic collector plate and the outside shield of the camera tube is largely neutralized.

Shielding precautions are very essential in these early stages of the video amplifier, since the wide band of acceptance of the amplifier includes the entire radio broadcast band. Consequently, any near-by radio station may induce, either inductively or capacitively, sufficient signal levels into these early stages to mask out completely the desired television signals if proper shielding is not employed.

A typical video amplifier stage is shown in Figure 12–15. Several cascaded stages, similar to the first tube shown, must be used in the preamplifier to raise the signals to a sufficient level, so as to allow transmission over a coaxial cable to the main control equipment. However, the relatively high impedances of even 1000 ohms would not be suitable for transmission over the large-capacitance coaxial cable. Therefore, a line amplifier type of tube is added beyond the early video amplifier stages. This tube is illustrated by the second tube in Figure 12–15. A stage of amplification utilizing a tube in this manner is called a cathode-loaded stage, and the impedance in this cathode circuit is matched to approximately 50 or 75 ohms, so as to send the signals without phase or frequency errors over 50- or 75-ohm coaxial cable. If the coaxial cable is to be long, the resistive load is generally placed at the far end of the cable away from the tube. However, for short runs of the order of a few feet it is satisfactory to place the resistive load for the cathode-loaded stage at the tube itself and to use the extra loading capacitance of the cable directly, without impedance loading at the far end. At the other end of the cable a volume control of 500 to 1000 ohms impedance may be employed to adjust the signal level of the output. Video line amplifiers designed to operate a long length of cable frequently employ several high-transconductance tubes in parallel.

These video signals must be amplified to a level of several hundred volts in order to modulate the transmitter properly. Many stages of video amplification are therefore required. One stage using a tube of high mutual conductance can realize only a voltage gain factor of 3 to 7, depending on the tube. Several branch-line video amplifiers are provided to accommodate a number of pick-up cameras and a number of picture monitor units as well as to supply the signals to the transmitter for radiation.

Several different sections of video amplifiers are generally employed in a television station to simplify the shielding problem and the power supply problem. The power supply must have a very low noise level and must have extremely good regulation. Figure 12-16 illustrates the basic principle of a typical regulated power supply. This type of electronic regulation compensates for line voltage fluctuation and for load current changes. It also minimizes the need for heavy filter circuits. The VR tube provides a fixed voltage drop across a gas discharge and serves as a reference voltage for the power supply. Any change in delivered voltage caused by line voltage change or by load current change tends to cause a change in voltage upon the grid of the pentode amplifying tube. This tube, in turn, applies a corrective signal to the grid of the several output tubes in parallel, so that the current delivered by these output tubes is altered to restore and maintain a fixed delivered load voltage. In the early video amplifier stages of the television camera a super-regulated supply is frequently used, employing several stages of electronic amplification in the voltage regulator circuits. A regulated power supply yields an apparent impedance of the order of 10 ohms, which is equivalent to the internal resistance of a good set of batteries. Consequently, very little feedback from later stages to the early stages can take place through such a power supply, and the video amplifier can be made stable even with high gain and wide frequency range.

De-coupling circuits consisting of resistors and bypass condensers to ground are employed in the supply circuits of both the plate and screen grid of the video amplifier stages. The bypass components generally consist of a small condenser for high-frequency purposes and a larger condenser for low-frequency filtering. It must be realized that a large capacitance with lead lengths of the order of a few inches can be resonant for frequencies within the video frequency bandpass region. Serious phase distortion in the early stages of video amplifiers may appear if the bypass condensers become defective. Frequently, if electrolytic condensers are employed, they may deteriorate with age and cause a phase distortion to creep into the amplifier, making itself apparent by trailing or streaks across the picture, wherein a black portion is followed by a whiter trailing going clear across the remainder of that line of the picture and sometimes even continuing into the next line.

Inductive peaking of video amplifiers is illustrated in Figure 12-15. For complete balance of the circuits, where even the slight changes in location of the wiring from unit to unit becomes serious, it is customary to employ peaking inductances having a small adjustability in range. Coils using a movable powdered iron slug are common. Square-wave testing and video wobbulator testing enable accurate adjustment of these peaking coils to obtain a wide-range response free of phase and amplitude distortion. Such test procedures will be described in more detail in a later section.

In certain preamplifiers for the video signals immediately following the camera tube, it is customary to employ a relatively high-impedance load resistor for the camera tube itself, in order to generate input signals to the first video amplifier tube of the order of millivolts. However, when this high-impedance load resistor is employed, the very-high-frequency components of the video signals are attenuated more than the low-frequency components. Thus in the second or third stage of the

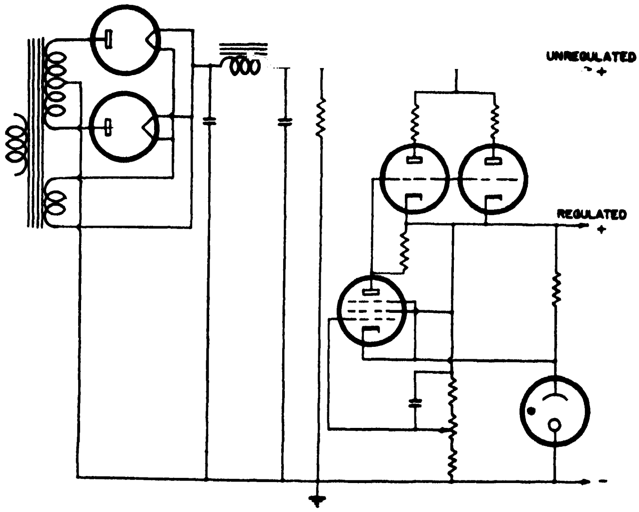

Fig. 12-16. Typical circuit of regulated power supply for video amplifiers.

video pre-amplifier a compensating network consisting mostly of inductance with very little resistance may be used to accentuate the high frequencies and thus restore a substantially flat frequency response. It is important that amplifier overload should not take place between the overemphasis of the low frequencies, and the subsequent compensation to overemphasize the high frequencies, providing an over-all flat characteristic.

In some types of camera tubes, part of the video amplification is achieved by using the secondary emission principles to yield electron multiplier action. In this way the electron multiplier operates at the low signal level to raise the signal well above the input noise level of the conventional vacuum tube, thus yielding a better ratio of signal to noise for the television system. A tube of the iconoscope type, while not using electron multiplier principles, does yield a storage effect in its mosaic, which thus provides a satisfactory signal-to-noise ratio of the video signals when the scene being televised provides sufficient light.

12–7. Shading Circuits—In certain types of television camera tubes, particularly the iconoscope, spurious signals may be generated within the camera tube, and these signals may be neutralized to some extent by artificial waveforms introduced as shading signals. These shading signals are required most often when the camera is operated under rather adverse lighting conditions. The spurious signals in the camera are generated as a result of the electron scanning of the mosaic, and as a result of the insulated nature of the islands of the mosaic. The electron beam, having its high velocity due to 1000-volt acceleration, strikes the islands and causes secondary electrons to be emitted. Those islands near the center of the mosaic will release their secondary electrons sometimes to nearby islands, as well as to the wall coatings of the bulb. However, those islands near the edges of the mosaic will release their secondary electrons largely to the conducting areas around the mosaic. Thus the "dark signals" delivered by the camera tube are not necessarily uniform for elements distributed over the mosaic. Central elements may deliver different signals from edge elements, even when no light is falling on the mosaic. These different signals thus seem to be video signals, and as such cause the receiving tube to show a variation in illumination over the scanned area. Now, when a scene is focused on the mosaic, its transmission is distorted by this spurious signal distribution. For example, the center of the picture may appear bright, and the scene may become gradually darker toward the top and toward the bottom. Now in the early stages of the video preamplifier, if there is introduced a sine wave of voltage of proper amplitude and phase, the illumination can be brought back on the receiving tube to a normal flatness, somewhat dimming the center and somewhat brightening the top and bottom. A sine wave thus introduced is called a shading signal and is usually inserted in the early video preamplifier stages. The requirements of shading signals differ from one camera tube to another, and therefore adjustability is necessary for the amplitude and the phase and the nature of the signals.

Figure 12–17 shows a typical set of camera control units. In this apparatus there is a cathode-ray oscillograph on which the composite video signals appear. Above the shading unit is a twelve-inch picture monitor unit which the operator also observes. By observation of the oscillograph and the monitor unit, proper shading may be provided.

The shading unit generates three waveforms for vertical scanning and three more waveforms for horizontal scanning shading. These three signals for each axis consist of: (1) sawtooth signals either positive or negative in polarity and variable in amplitude; (2) sine-wave signals adjustable in phase and amplitude; and (3) parabola signals available in either positive or negative polarity and adjustable in amplitude. The parabola signal is derived from a sawtooth waveform and is used for adjusting the brightness of the center with respect to the top and bottom in case of vertical scanning, or adjustment of the center with respect to the left and right sides in the case of horizontal scanning.

To a limited extent, these shading signals may be employed to compensate for deficiencies in the uniform distribution of lighting in studio scenes or in motion picture records, although the primary purpose of shading signals is to compensate for the spurious signals generated in the camera tube. The shading signals may also be used by the program director to produce certain artistic effects. The sine-wave shading signals are sometimes helpful in neutralizing power supply voltages introduced in the system.

Certain camera tubes such as the orthicon with its low-velocity beam and the dissector tube require very little, if any, shading.

12–8. The Synchronizing Generator—For a television system to produce steady pictures it is vital that synchronism of scanning be maintained between the various pick-up cameras, the station monitor equipment, and all of the television receivers in the field. The synchronizing generator is therefore one of the most important units in the entire television chain. This unit provides control signals to regulate the scanning circuits in the cameras, the monitor tubes, and to control those synchronizing signals radiated by the transmitter for regulation of the scanning at the receiving points.

In order to understand more clearly the synchronizing problem it is worthwhile to make a careful study of the composite television waveform which is radiated by the transmitter. In Figure 12–6 is shown a standard radiated waveform for 525-line

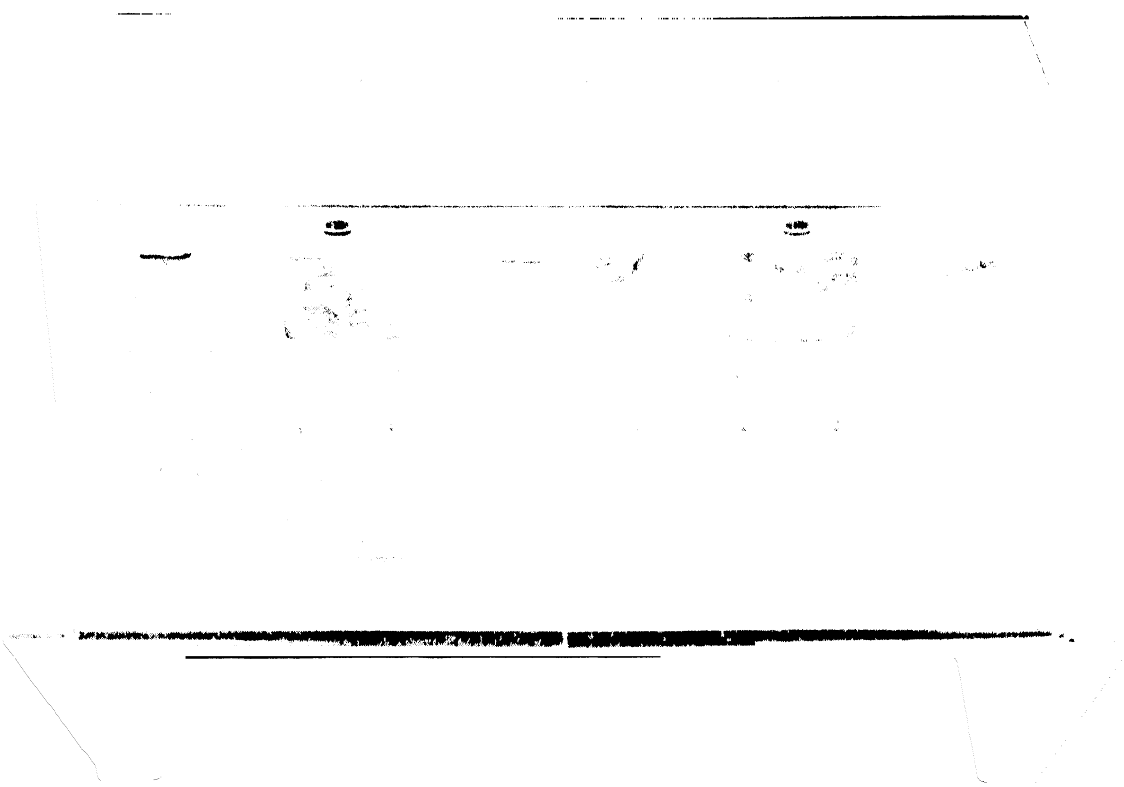

FIG. 12–17. View of studio or motion-picture control units illustrating shading circuits, as well as waveform and picture monitors.

scanning. Later figures show cathode-ray oscillograph photos of television waveforms.

Referring to Figure 12–6, the waveform radiated by the television station consists of three basic parts. The first part is the video signal which occupies that voltage region between zero carrier voltage and 75-percent carrier voltage. This part of the signal corresponds to receiver cathode-ray tube brightness all the way between maximum white in a picture and just black of the picture, which corresponds to zero beam current.

The second necessary component in the radiated waveform is the horizontal synchronizing information which is placed in that carrier voltage region between 75 and 100 percent of the maximum carrier voltage radiated by the station. These horizontal synchronizing signals are short pulses of energy occurring at the end of each scanning line and having a repetition rate equal to the horizontal line repetition rate (for example, 15,750 lines per second).

The third fundamental component in the radiated waveform is the vertical synchronizing information. It also is transmitted in the carrier amplitude range between 75 and 100 percent. Since the vertical synchronizing information has a low frequency repetition rate (for example, 60 pulses per second), and the horizontal synchronizing pulses have a high frequency repetition rate (for example, 15,750 pulses per second), it is possible to transmit both of these components in the same amplitude range and to utilize them independently in the receiver circuits by means of frequency selection. The vertical synchronizing information must be interrupted at regular intervals in order that the horizontal pulses may be continuous for the line scanning during the vertical blanking interval. In this waveform the vertical synchronizing signal consists of a series of six pulses of longer duration than the horizontal synchronizing pulses. Therefore the energy in the six pulses can integrate through a low-frequency pass circuit to produce a single pulse useful for vertical synchronization. Such a low-pass circuit will be relatively insensitive to the lesser energy contained in the short-duration horizontal pulses.

The television system employing interlace principles must produce vertical synchronizing signals timed to an accuracy of a small fraction of one line on successive vertical scans. Consequently, in Figure 12–6, waveform 1 illustrates the vertical synchronization for a given field of vertical scanning, while waveform 2 of Figure 12–6 illustrates the vertical synchronizing signal for the next succeeding vertical field of scanning. The time differences between time t_1 at the start of the vertical sync pulse and time $t_1 + V$ at the start of the next vertical sync pulse must be precisely the vertical scanning interval (for example 1/60th of a second).

Reference to the definitions of television line, field, frame and interlace may be helpful at this point. As an example, a 525-line television system employs 525 scanning lines per complete television frame or picture. If thirty complete pictures per second are formed, then 30 × 525 = 15,750 lines per second. Since 525 is an odd number, then a vertical scanning rate of sixty fields per second will divide the 525 lines into two groups of lines of 262½ lines each. This half line left over on each field scan thus fits successive field scanning patterns into one another in an interlace fashion, giving a finer resolution to the picture. The primary purpose of interlacing, however, is the production of a scanning pattern which has the relatively high vertical scanning rate, for example, of sixty fields per second, which yields little or no observable flicker even with the intermittent scanning action. With this vertical scanning frequency of sixty fields per second it would be possible to produce the same ultimate detail of 525 lines by producing 525 horizontal scans in each sixtieth of a second, but unfortunately this would greatly increase the upper limit of video frequencies required to transmit pictures having good horizontal resolution, since the lines per second would be doubled. Therefore, by employing the interlace system producing thirty complete pictures per second, the video frequency requirements are not so difficult and at the same time freedom from flicker is achieved. Continuity of motion is portrayed, since the total picture frequency is maintained at thirty per second.

In order to provide accuracy of interlace, the synchronizing waveform contains certain double frequency equalizing pulses immediately preceding, during, and immediately following the vertical synchronizing pulse interval. These double frequency pulses serve to cause the vertical synchronizing selector circuits to operate precisely for interlace to a greater degree than if only the regular horizontal pulses continue during the vertical synchronizing interval. If equalizing pulses were not used, then on one interlace field scan the horizontal pulse immediately preceding the vertical synchronizing pulse interval would be a whole line away, while on the succeeding interlace field scan the preceding horizontal pulse would be a half line away. It has been pointed out that the horizontal pulse does not integrate to appreciable energy; yet such energy, as it does contribute to the vertical selector circuit, would be sufficient to throw off the accuracy of interlace if the double frequency principle were not employed for a few lines before, during and after the vertical synchronizing pulse interval.

It is imperative that the uniformity of occurrence of the rising edges of the horizontal synchronizing signals be maintained to a high order of accuracy. Otherwise some lines would be longer than others in time, and the received picture would not fit together very well. The details of the tolerances on the television waveforms are shown more clearly in curves 3, 4 and 5 of Figure 12–6.

In addition to the video waveform and the vertical synchronizing signals the composite waveform also contains blanking signals at both vertical and horizontal frequencies. These might be treated fundamentally as part of the video signal, since it is necessary to turn off the beam in the receiving tubes while the beam retraces to the starting point for the next line or field. However, these blanking signals perform a useful synchronizing function as well. The blanking signals are so introduced that they generate a small "front porch" or flat region at the black level just ahead of the horizontal or vertical synchronizing interval. The blanking signal continues during the entire time of the horizontal or vertical synchronizing interval. Then the blanking signal is completed by producing another flat region at black level, called the "back porch." This composition of the blanking signal is more clearly shown for the horizontal signals in curve 3 of Figure 12–6. This front porch is important in providing a uniformity of the synchronizing pulses, as seen by the synchronizing selector circuits. Without this front porch, then, the immediately previous picture content, if largely white, would produce a slightly different timing of the synchronizing pulse than if the immediately previous picture information had been largely black.

In the receiver circuits the synchronizing information is first led into a separate channel by amplitude separation from the video signals. Then the skimmed-off synchronizing waveform is fed to further selective circuits which isolate the horizontal information from the vertical information, using some form of frequency selectivity. In this way clean horizontal synchronizing signals may be fed to control the horizontal scanning circuits, and clean vertical synchronizing signals may be fed to control the vertical scanning circuits. The entire signal, including video, blanking and synchronizing, is fed to the receiving cathode-ray tube for picture modulation of the grid. The presence of the synchronizing signals does not disturb the visible picture, since these signals are in an amplitude region beyond grid cut-off for the cathode-ray tube, and thus the synchronizing excursions correspond to the "blacker-than-black" region of the picture.

An important difference between television signal modulation of the radio-frequency carrier and sound signal modulation of the radio-frequency carrier should be emphasized at this point. The television transmission is accomplished by amplitude modulation. In sound broadcasting using amplitude modulation, the carrier envelope is modulated for a balanced increase and decrease of instantaneous carrier level about an average carrier value.

The amplitude modulation for television transmission does involve both positive and negative excursions of the radio-frequency carrier voltage. The television signals observed at radio frequency will therefore oscillate symmetrically about a center line of zero voltage, as will be more clearly shown in later oscillograms.

In sound broadcasting, however, the r-f excursions occur symmetrically about a center line of zero voltage and for an absence of sound in the microphone there is a fixed carrier level of r-f voltage. Then the presence of a weak sound causes a small modulation about this carrier value, momentarily increasing and then decreasing the instantaneous carrier level. A louder sound causes greater excursions of the envelope about this average carrier level. The loudest sounds cause the carrier energy to go through excursions from twice the average carrier amplitude down to zero carrier amplitude.

However, in the transmission of pictures it is necessary to produce what might be termed a single-ended signal. In other words, the receiver cathode-ray tube must produce visible signals starting at black and working in one direction upward in brightness toward maximum white. Careful observation of the television waveform in Figure 12–6 will show that the transmission system employed in the United States may be called negative transmission, since decreasing radio-frequency carrier amplitude corresponds to increasing brightness of the picture being televised. Nevertheless, the television transmitter operates with single-ended amplitude modulation rather than with balanced modulation about an average carrier. In practice, the reference level for the television waveform is the peak of synchronizing which is termed 100 percent or maximum carrier voltage. This level must be maintained at a fixed field strength throughout the entire transmission. In fact, the waveform of the synchronizing components in the range from 75 to 100 percent carrier amplitude is maintained at a constant level throughout the transmission, independent of the changes in scenes being televised.

In the television system it is therefore necessary to transmit the average brightness content of the picture as well as the variations in shade along each line horizontally and along each field vertically. This system of d-c transmission of the average brightness involves certain d-c inserting devices at the transmitting equipment and at the receiving equipment. In particular, the video amplifier must be connected to the cathode-ray tube grid in such a way that the changes in video content of the television waveform work from the black level or grid cut-off point always toward increasing beam current and never beyond grid cut-off during the picture intervals. In sound amplifiers it is customary in the amplifier tubes, and even in the loud-speaker, for the voltage to oscillate about an average value, going both positive and negative with respect to this average value. In the cathode-ray tube, however, no picture advantage is achieved by swinging beyond grid cut-off, except for the purpose of blanking and synchronizing mentioned above. During the picture interval the signals must start from the black level as reference and work toward white, depending upon the particular content of the scene being transmitted.

Because of this single-ended nature of television modulation, it is best to rate television transmitters in terms of peak power, rather than root mean square, or rms, power. Peak power stays substantially constant, independent of picture content, whereas the average power radiated is much greater for a nearly black scene than for a white scene. This is quite different from the case of amplitude modulation sound broadcasting, where both the peak power and the rms power remain substantially constant, independent of degree of modulation. Further discussion of power considerations will be covered later.

Now that the radiated signal has been described in some detail it will be helpful in connection with the synchronizing generator to discuss the methods whereby these accurately timed pulses, blanking signals and video signals are generated and combined. Figure 12–18 shows a synchronizing generator block diagram illustrating the frequency divider stages and the shaping circuits. The actual figures on this diagram illustrate a 525-line television system producing 525 lines per picture and 30 pictures per second. The synchronizing generator has a master oscillator operating at 157.5 kc per second which is 10 times the line frequency. This choice of the master oscillator frequency permits generation of linearity bars. It is evident that the system could be designed around a master oscillator frequency of 31,500 cycles per second. This 157.5-kc master oscillator actuates a 10:1 frequency

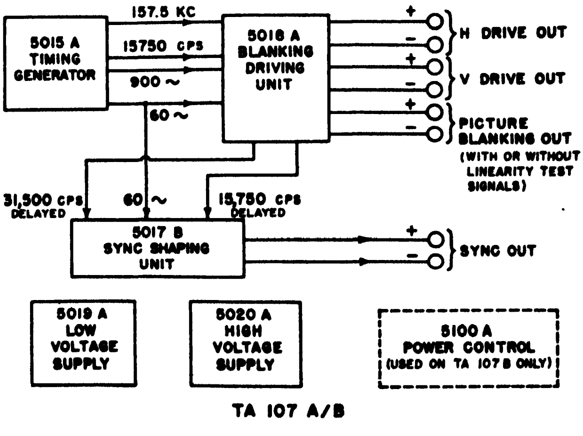
157.5 KC
5015 A TIMING GENERATOR
15750 CPS
900 ~
60 ~
5018 A BLANKING DRIVING UNIT
+
−
H DRIVE OUT
V DRIVE OUT
PICTURE BLANKING OUT (WITH OR WITHOUT LINEARITY TEST SIGNALS)
31,500 CPS DELAYED
60 ~
15,750 CPS DELAYED
5017 B SYNC SHAPING UNIT
SYNC OUT
5019 A LOW VOLTAGE SUPPLY
5020 A HIGH VOLTAGE SUPPLY
5100 A POWER CONTROL (USED ON TA 107 B ONLY)
TA 107 A/B

FIG. 12–18. Synchronizing generator block diagram illustrating frequency divider stages and shaping circuits. (Courtesy DuMont.)

divider stage. There may be a simple 10:1 count or a combination of 5:1 and 2:1 to produce a signal at the line frequency of 15,750 cycles per second. These line-frequency signals go to a waveform shaping unit which converts these master signals into the square-shaped pulses for horizontal synchronizing and into the blanking signals. Pulses of a frequency of 31,500 cycles per second must be utilized as well as the line freqpency pulses because of the requirements of the equalizing signals.

Now, going back to the master oscillator, another chain of frequency dividers is employed. The purpose of this chain of dividers is to derive from the master oscillator frequency the control pulses for field frequency at 60 cycles per second. It is imperative that this oscillator at twice line frequency be very precisely related to the field-frequency pulses. Therefore, by means of the divider stages the field-frequency signals are generated from and tightly locked in with the master oscillator. The 157.5-kc oscillator drives a 5:1 divider stage, yielding 31,500 cycles per second which is twice the line frequency of 15,750 lines per second. Then four divider stages are used having divisions of 5, 5, 7, and 3 per stage, respectively, yielding a field frequency of 60 cycles per second. The product of $5 \times 5 \times 7 \times 3$ is 525. Since this is an odd number and since the 31,500-cycle oscillator period corresponds to ½ of a line interval, then successive field-frequency pulses will differ in their starting point on the final television scanning raster horizontally by displacement of ½ line. This half-line horizontal displacement thus will cause successive vertical scanning patterns to be interlaced with one another. Actually the synchronizing generator is not required to provide a 30-cycle output.

If the master oscillator is crystal controlled, then the derived field-frequency pulses at 60 pulses per second is sufficiently precise for practical purposes. However, it is common practice in a television station to use an automatic frequency control, or AFC, circuit which compares the derived field frequency signals at 60 cycles per second with the power line signals at 60 cycles per second. This comparison circuit employs a discriminator in which a voltage is generated depending upon the phase relation between the field frequency of 60 cycles per second and the power-line frequency of 60 cycles per second. This generated voltage is then fed back to a reactance tube or other frequency-controlling element associated with the master oscillator. Such control voltage, however, is made to operate through circuits having long time constants which simulate large inertia. In this way, the line-frequency and field-frequency signals are caused to be loosely locked with the power-line frequency and they will maintain a certain average phase relationship to these power line signals. However, with the long time constant circuits any sudden surges of the power line, lasting only a moment, will have very little influence on the synchronizing generator frequency. There are advantages from this tie-in between the synchronizing generator and the power source used for the transmitting equipment. The choice of power frequency for vertical scanning field frequency enables simpler neutralization of power-frequency hum introduced by lighting or in the video amplifiers. Perhaps the most important advantage, however, of this tie-in is connected with motion picture transmission by television. The projector must be carefully synchronized with the scanning process and thus a synchronous motor operated from the power line can be kept locked in satisfactorily with the scanning process. Further details of the motion picture problem will be discussed in a later section.

Referring again to the block diagram of Figure 12–18, the several sets of pulses pass to the waveform shaping circuits. In these shaping circuits the pulses at twice line frequency, the line-frequency pulses, and the field-frequency pulses are combined with suitable squaring stages and time delay circuits to generate the blanking signals, the horizontal synchronizing pulses, and the complex vertical synchronizing information, yielding the composite synchronizing waveform of Figure 12–6. Separate blanking signals and driving pulses are delivered by these shaping circuits, to be utilized in the iconoscope, image orthicon, or other style of camera tube, for turning off its scanning beam during its re-trace time.

It is customary in some systems to provide horizontal driving pulses from these shaping circuits to control horizontal scanning action in the cameras and in the station monitor units. Separate vertical driving pulses may be generated also and used for camera and monitor control. In other systems these waveform shaping circuits actually deliver the sawtooth scanning voltages for horizontal and vertical scanning in the cameras and monitor equipment.

The performance of equipment is rather critical as to the precision of the synchronizing waveshapes. In particular the duration of the front porch signals must be maintained precisely, and the uniformity of the horizontal pulse leading edge repetition rate must be maintained.

The television synchronizing generator feeds blanking signals to the several camera chains in a station. Then the composite synchronizing signals in the range from 75 to 100 percent amplitude, usually called super-sync, may be fed into the control circuits after the blanking and video signals have been combined. In the operation of several cameras the length of cable between synchronizing generator and the camera and back to the master control system is generally not the same for all cameras. The front porch interval for horizontal synchronizing is only 2 percent of a horizontal pulse interval. This 2 percent amounts to only 1.27 microseconds in time, as can be seen from the table showing data on the

FIG. 12–19. TABLE OF DATA ON F.C.C. TELEVISION WAVEFORM FOR 525-LINE, 30-FRAME SYSTEM

No.	Description	*Duration in microseconds	*Relation to other units
1	Frame	33,333	30 c.p.s. 2 V = 525 H
2	Vertical field interval (=V) (see Fig. 12–6)	16,667	60 c.p.s. V=262.5 H
3	Equalizing pulse preceding vertical sync. pulse	190.5	3 H
4	Vertical sync. pulse interval	190.5	3 H
5	Equalizing pulse following vertical sync. pulse interval	190.5	3 H
6	Leading and trailing edges of equalizing pulse interval	.254 max.	.004 H max.
7	Leading and trailing edges of vertical sync. pulse interval	.254 max.	.004 H max.
8	Interval between equalizing pulse and vertical sync. pulse	29.21	.46 H
9	Rising and falling slopes each of vertical blanking interval	<6.35	<.1 H
10	Vertical total blanking	833.4	.05 V=13.125 H
11	Vertical picture time	15,835.3	.95 V=249.375 H
12	Horizontal line interval (=H)	63.5	Line freq.=15,750 c.p.s.
13	Horizontal blanking interval	10.2	.16 H
14	Horizontal front porch	1.27	.02 H
15	Horizontal super sync. width at bottom	5.08	.08 H
16	Horizontal super. sync. width at top	4.57	.072 H
17	Front slope horizontal super sync.	.25 max.	.004 H max.
18	Back slope horizontal super sync.	.25 max.	.004 H max.
19	Horizontal line picture interval	53.3	.84 H
20	Picture duty cycle per frame	25,900	77.7% in time
21	Total blanking time per frame	7,433	22.3% in time
22	Max. slope end of picture to start of horizontal blanking	.64 max.	.01 H max.
23	Max. slope end of horizontal blanking, start of picture	.64 max.	.01 H max.
24	Sync. generator master oscillator (period)	31.75	twice line freq. or 31,500 c.p.s.
25	Zero carrier	–	Zero ref. level for video signal (whiter than white)
26	White level	—	Capable of 15% or less of peak carrier amplitude
27	Black level	—	75% of peak carrier amplitude
28	Peaks of synchronizing		blacker than black 100% amplitude

* The specific values given in this table are the median values where tolerances are specified in drawing.

television waveform for a 525-line 30-frame system. Now the propagation time for signals going over a length of average coaxial cable is approximately one-tenth microsecond per one hundred feet. Therefore, it is necessary to compensate for the different lengths of cables to the different cameras in order to maintain the precision of tolerances on these waveforms. In some equipment it may be possible to arrange the cables so that they are nearly enough the same length for the several cameras, so that no compensation is required when switching from one camera to another. Artificial delay circuits for the signals from a short cable can match the results from another camera using a longer cable. Adjustable delay for the scanning pulses of each camera is perhaps the simplest means of maintaining the desired precision.

Some convenient data are shown in Figure 12–19. In some stations it is more convenient to use several synchronizing generators because of this time delay problem in cables. Generally a remote pick-up unit will employ its own synchronizing generator independently of the studio equipment. Certain types of receivers with very long time constant control of the local scanning oscillators are subject to momentary surges in the scanning if the synchronizing generators are not carefully interlocked prior to switching, for example, from a remote pick-up program to a studio program.

12–9. Master Control Circuits—A complete television station is provided with several points at which control operators may adjust and schedule the various cameras which are utilized in making up the composite program. The picture signals must be adjusted for the one or more cameras in the studio. Then the signals must be adjusted for the motion picture television cameras. Also the signals must be balanced and adjusted from remote pick-ups brought to the central control points by coaxial cable or by wireless relay. Then, finally, signals from each source must be brought to a common point where they are monitored for operation of the main broadcast transmitter. A typical master control lay-out is shown in Figure 12–20, a functional diagram of the Du Mont TA–134–A master control system.

With these requirements it is common practice to provide several engineering control points for the television signals. They will be described, however, for studio control, master control, and transmitter control points. The studio control equipment has been described briefly in connection with the shading circuits. In addition to shading of the camera, it is necessary at the studio control point to direct the studio programming, and here the program director has control of the one or more cameras active in the studio. Each camera has its independent picture monitor at the control desk, so that the program director may select that scene chosen for the outgoing transmission from the available cameras. Also, he may preset the remaining cameras for proper program balance before they are switched to the outgoing line. Individual signal level controls are provided in each camera circuit. The oscillographs enable the technical operators to accomplish proper shading and maintain a full level of signal within the 0 to 75 percent of amplitude range which can be devoted to the picture components, thus balancing all cameras to the same relative signal level. The program director, by simple push-buttons or dials, may select any one of several cameras. By use of mixer tubes, the output signals from two or more cameras may be blended with one another so as to allow gradual fading out of one camera while a new camera comes up in signal level. For certain artistic purposes the mixer input circuits from two cameras, for example, may be set at half-gain value, both pictures being thus superposed on the outgoing line. In the studio control equipment one picture tube monitors the outgoing line signal for study by the program personnel.

In this studio control equipment intercommunicating phone systems are incorporated, so that the technical director and the program director may talk with the studio operating crew, consisting of the sound microphone boom man, the lighting man, the studio director, the camera men, and others. This same intercommunicating system is connected with the master control board, the transmitter room, the motion picture projection room, and other points in the television station.

The master control room frequently is separate from the studio control desks, since individual studios may be used for rehearsal purposes while the master control system is being used for broadcasting from other picture sources. The synchronizing generator equipment, the line amplifier equipment, the motion picture pick-up cameras, certain of the sound equipment, and the monitor apparatus are located in the master control room. The synchronizing generator distributes its control signals to the several cameras in near-by studios and to the motion picture equipment. It also supplies control signals to the picture monitors and to the mixing amplifiers, where the composite synchronizing waveforms are combined with the several picture signals.

The master control desk may contain the shading circuits, the gain controls and the switching facilities for operation of the motion picture equipment. A television receiver operated from an antenna, placed to obtain a signal from the broadcast antenna, provides a continuous monitor of the transmitted pictures and sound. Figure 12–21 shows panels of master control equipment. Many coaxial

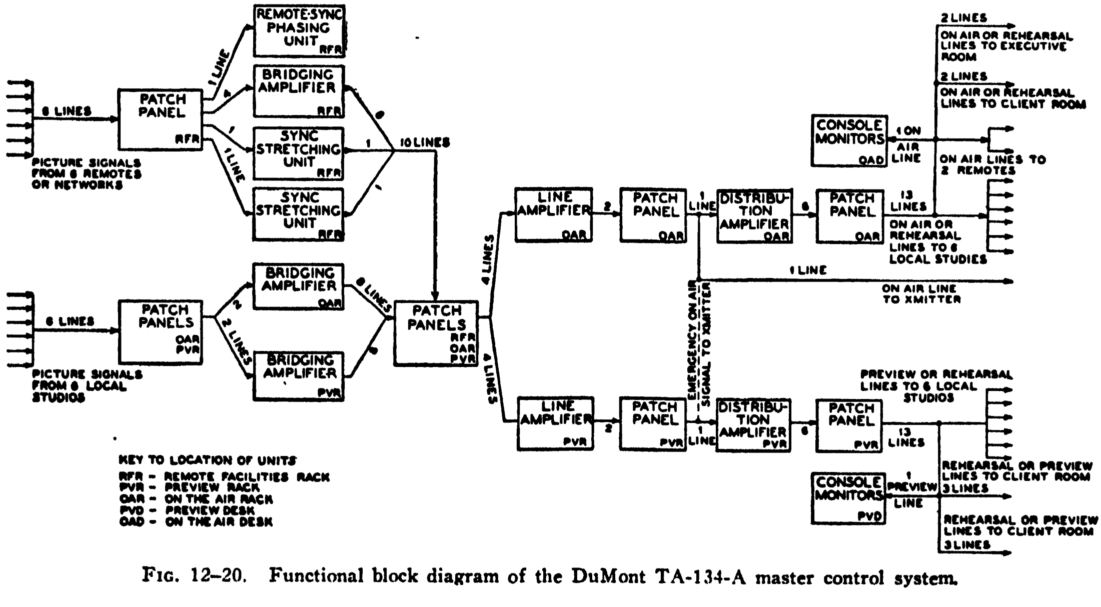

Fig. 12–20. Functional block diagram of the DuMont TA-134-A master control system.

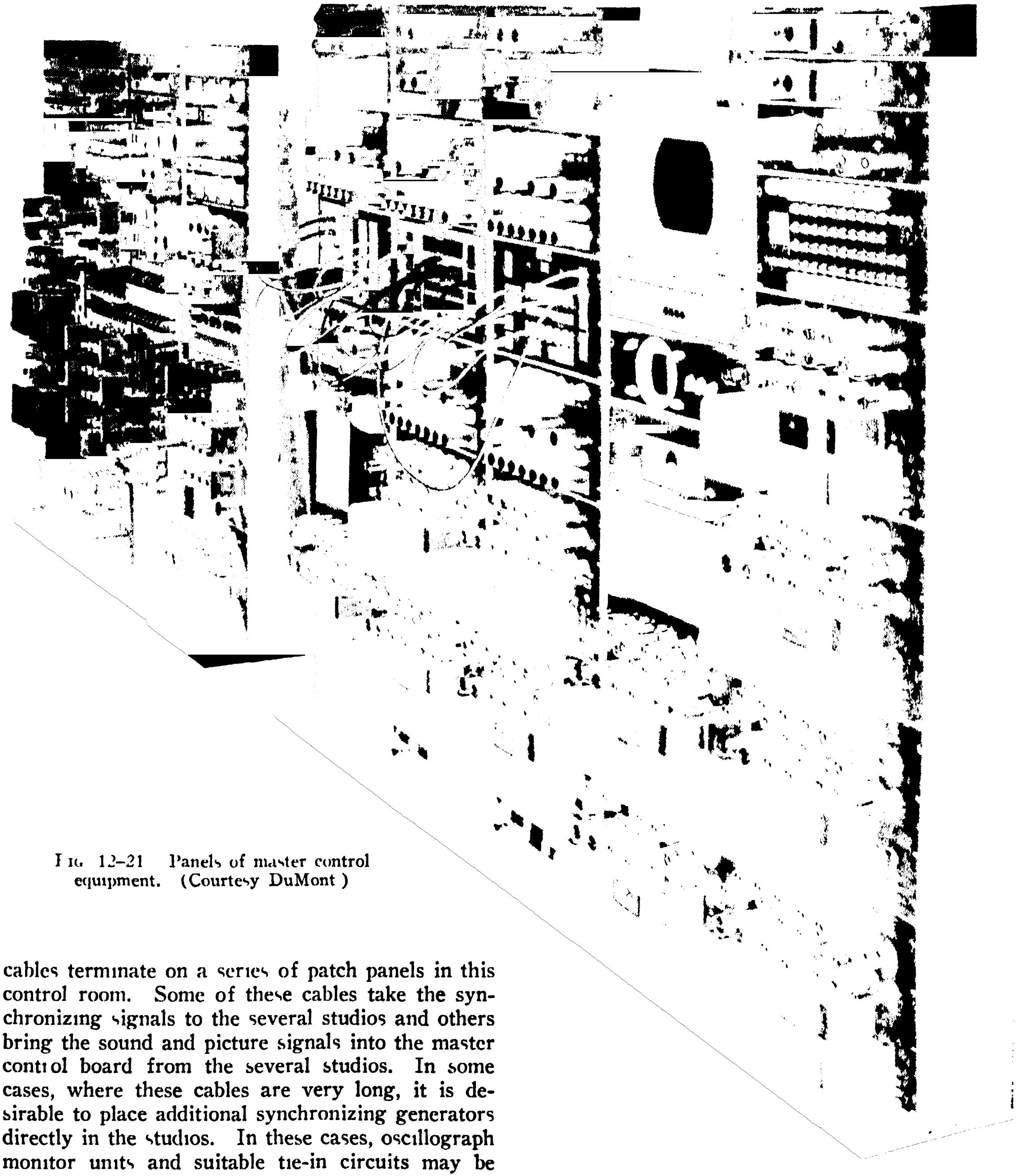

FIG. 12-21 Panels of master control equipment. (Courtesy DuMont)

cables terminate on a series of patch panels in this control room. Some of these cables take the synchronizing signals to the several studios and others bring the sound and picture signals into the master control board from the several studios. In some cases, where these cables are very long, it is desirable to place additional synchronizing generators directly in the studios. In these cases, oscillograph monitor units and suitable tie-in circuits may be utilized to bring these remote synchronizing generators into step with the master synchronizing generator to provide the least surges when switching between studio circuits and motion picture circuits.

It is desirable that the studio cameras, the motion picture cameras, and the control desks be placed at a reasonable distance from the main transmitter, so that the radiation from the high-level stages of the transmitter may not feed back into these circuits and cause instability.

12-10. Picture Monitor—The picture monitor units are essentially television receivers without the i-f circuits. Some of the monitors in the station are driven directly from the master synchronizing generator for control of the scanning circuits. In this way there is no interruption of the scanning while switching picture signals from one circuit to another. Other picture monitors receive both the synchronizing signals and picture signals from the picture amplifiers directly, in order that they may provide adequate monitoring of the overall signals

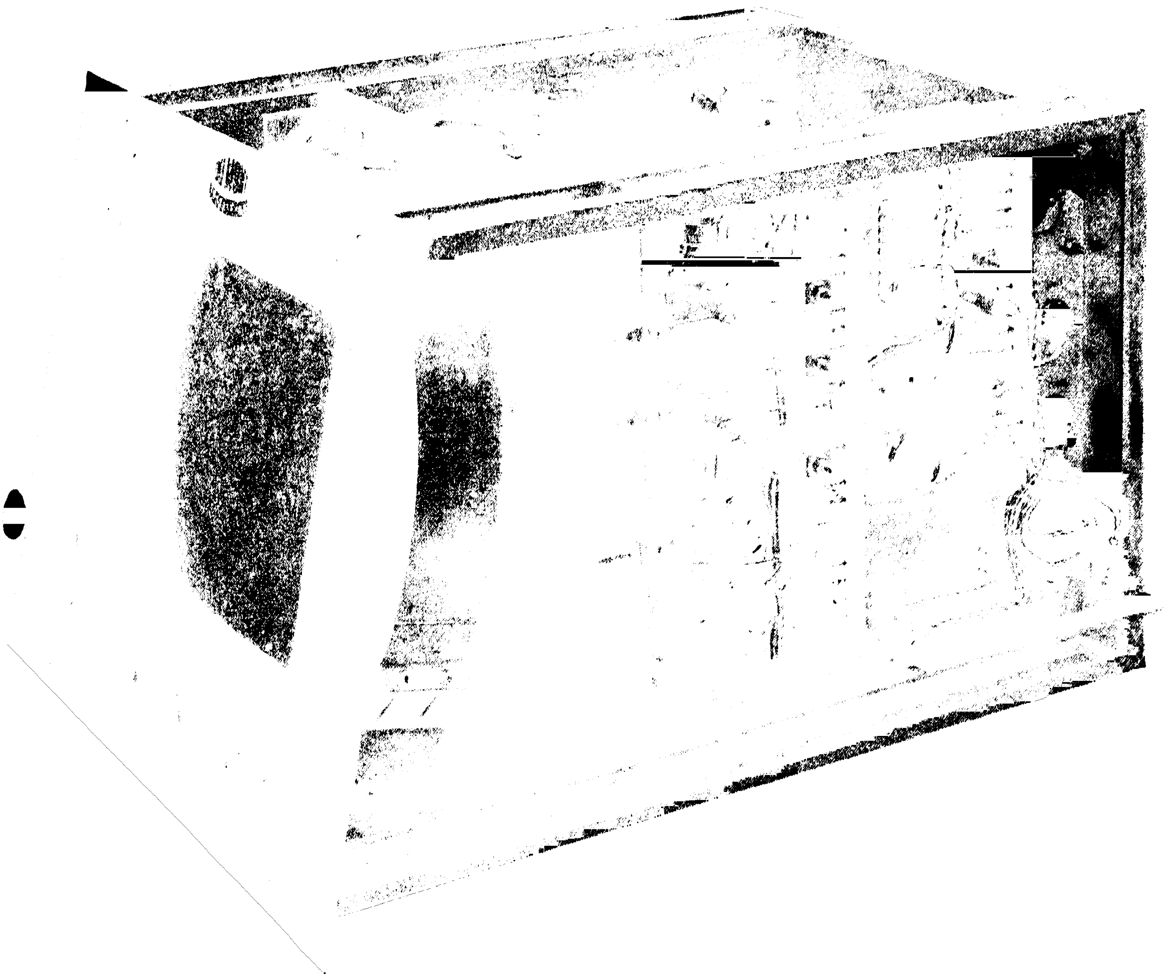

FIG. 12–22. Twelve-inch picture monitor with cover removed.

intended for the transmitter. The picture monitors utilize small tubes of about 5 inches diameter where compactness is necessary as, for example, on the electronic view finders attached directly to the pick-up cameras. The small monitors are convenient also for portable remote pick-up equipment. The larger monitor tubes of twelve, fifteen or twenty inches diameter are preferable in the studio control equipment where the program director must observe the artistic details while composing and directing the production. The larger monitors are used also in the master control equipment, the motion picture circuits, and the transmitter room monitoring circuits. Additional monitors may be placed in audience rooms throughout the station. Figure 12–22 shows a twelve-inch monitor with cover removed.

A picture monitor unit consists of a low-voltage power supply, a high-voltage supply, the synchronizing circuits, the deflection circuits, the video amplifiers, and the cathode-ray tube. The low-voltage power supply delivers approximate voltages of 250 volts regulated and 400 volts unregulated for the video amplifier stages and for the deflection circuits. The cathode-ray tube high-voltage supply ranges from 5000 volts to 20,000 volts, depending upon the size of the monitor. These monitor units may employ either electrostatic deflection or electromagnetic deflection for the cathode-ray tube. More details of the operation of synchronizing circuits, the deflection circuits, and the video amplifiers applicable also to picture monitors, are provided in the section describing receivers. Controls are provided to adjust cathode-ray tube focus, brightness, picture contrast or video signal level, horizontal scanning speed, horizontal picture size, vertical scanning speed, and vertical picture size.

The scanning pattern produced on a television picture monitor is called a "raster." It is convenient on at least one of the monitors in a television station to be able to adjust the size and scanning speed of both horizontal and vertical deflection over a rather wide range in order to study the com-

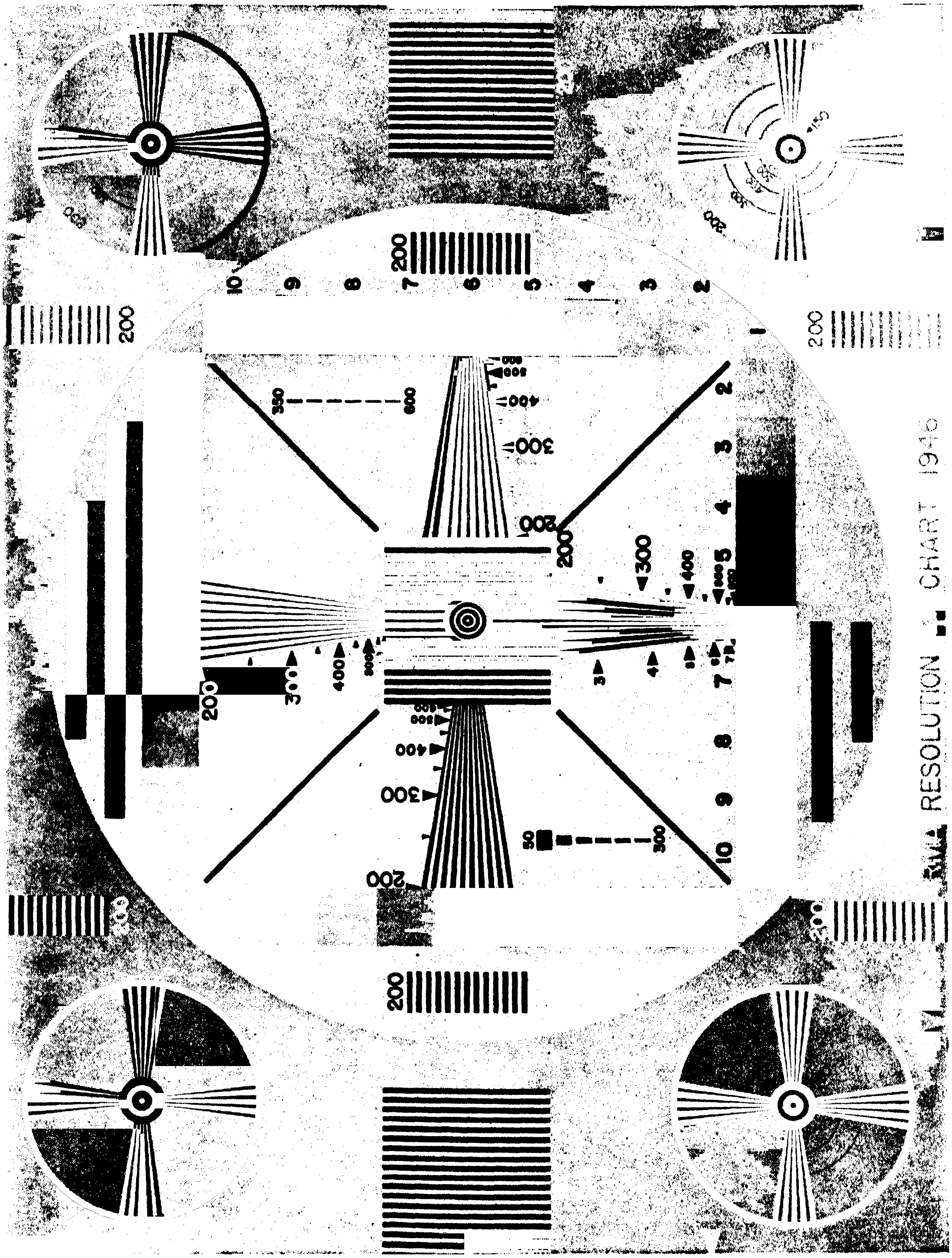

FIG. 12–23. RMA resolution chart used for engineering tests.

posite television signals carefully. In this way the picture monitor can be used to good advantage to supplement the cathode-ray oscillograph monitor units in making certain that the standardized waveforms are being produced. For example, if the horizontal scanning speed is adjusted to one-half the regular number of lines per second, then two pictures appear, one beside the other. In the center of the pattern will appear a dark region. By suitable adjustment of the contrast control and brightness control, this dark region may be studied and will be found to contain the horizontal blanking signals consisting of horizontal front porch, horizontal super-synchronizing pulse, and horizontal back porch. It is only by this half-speed scanning process that this horizontal blanking region may be shown with uninterrupted detail, since with the normal scanning pattern a portion of this blanking occurs at the right-hand side of the picture, and another portion occurs during the scanning re-trace time, and the final portion occurs at the left-hand side of the picture. If this special monitor unit having its wide flexibility of control is equipped with circuits providing excellent linearity of scanning, then the per cent blanking time, front porch, super-synchronizing and back porch may be measured by means of this observation. It is possible to compare the relative time delay between signals from several cameras by observing them one after another, or blended on the input circuits to such a monitor.

Likewise, if the vertical scanning frequency is dropped from its usual 60 cycles per second down to half speed, or 30 cycles per second, then there appear two pictures, one above the other. If horizontal scanning is at half speed, then a total of four pictures will appear. Thus it is possible to observe and study the vertical blanking interval and to monitor its distribution as to front porch, vertical super-synchronizing, and back-porch intervals.

On this special monitor unit, if the deflection circuits and power supplies are very stably designed, a picture using normal horizontal and vertical scanning frequencies may be observed carefully for accuracy of interlace. For example, the vertical amplitude may be increased to three or four times its normal value, causing the top and bottom of the picture to be way off the tube. However, the center portion of the picture can then be resolved into individual scanning lines on which the interlace can be observed. Poor interlace may be caused by inaccuracy either at the cameras or at the picture monitor. If this monitor is carefully designed, then it is possible to use it as a means of determining the relative perfection of camera interlace in the observation of the signals from the several cameras in the station.

Another useful purpose of the picture monitor is to enable the adjustment of proper linear distribution of vertical and horizontal scanning in the several cameras. It is desirable that the linear distribution of scanning be maintained on all cameras so that stationary scenes may be rendered in their proper proportions and, even more important, so that moving objects in a picture will not tend to become foreshortened or stretched out as they move from region to region on the scene. In testing for this linearity and for adjustment of proper aspect ratio in the several cameras, a special type of pattern called a test pattern is projected into the camera. This test pattern frequently consists of concentric circles, regions having steps of density all the way from black through several steps of gray to white, and portions showing radial wedges. Such a test pattern is shown in Figure 12–23, being a resolution chart prepared by industry engineers through the Radio Manufacturers Association. It is of value to have the test pattern in symmetrical form and with proper boundaries having the desired aspect ratio of three units height to four units width. When this test pattern is focused optically on to the camera tube mosaic, the camera scanning may be adjusted so as to just cover the test pattern, insuring thereby the proper aspect ratio. Then special calibration pulse signals may be introduced into the video amplifier circuits from the synchronizing generator.

These pulse signals are derived from the divider stages in the master synchronizing generator and are called linearity test bars when they appear on the tube. The linearity test bars have large markers at uniform intervals, with smaller marks appearing more frequently in between the large marks. In this way uniform time interval marks are provided on the monitor. They assist in adjusting the camera scanning independently of the monitor scanning. The monitor scan may first be adjusted for absolute linearity by use of these timing markers. When its scanning circuits are linear, both horizontally and vertically, then the test pattern may be reproduced on the monitor. If it appears nonlinear, it is necessary to readjust the camera scanning to correct this error. Without the use of these linearity test pulses, it would be difficult to decide whether poor linearity of the final observed picture might be caused by faulty scanning in the camera or the monitor, or a combination of both. It might be possible to obtain a good test pattern on the monitor by compensating errors of scanning in the camera and the monitor, although this condition can be detected and remedied by use of the linearity test bars. When the test pattern, having its stepped density tablet portion, is observed on the monitor, the proper balance of picture contrast and brightness may be adjusted so as to study these steps of contrast. Then the camera tube beam current and camera pre-amplifier gain controls must be so adjusted that the full range of contrast can be handled by the camera without saturation or overload. If a test pattern contains the extreme ranges of brights and shadows which it will be expected to transmit from the studio, then these cameras may be preset on this test pattern and will be ready for studio operation with very little further adjustment. By observation of the monitor, it can be seen that the camera becomes more sensitive to a given studio lighting condition as the beam current is raised. However, the rise of beam current begins to decrease camera resolution since increasing camera beam current generally is accompanied by an increase in camera spot size. This variation of resolution is best observed on the resolution wedges of the test pattern.

The accuracy of camera interlace can be studied by observing the test pattern wedges which run in the horizontal direction. The sharpness of focus of the camera tube and the high frequency response of the video amplifiers may be studied by observing the resolution wedges which run in the vertical direction. In order to obtain best camera tube beam focus for highest resolution, it is frequently desirable to expand the monitor tube scanning considerably, so that the wedge which runs vertically is spread out to where the spot size of the monitor cathode-ray tube is no longer the limiting factor for resolution. In like manner, for a test pattern having a given resolution in the finest portion of its wedges, say of 500 lines, it is sometimes desirable to decrease the camera tube scanning to, say, one half amplitude, thus apparently enlarging this wedge to twice its normal size. In this way a wedge designed to give 500-line resolution for a full-scanned picture will become substantially a thousand-line wedge under this half amplitude condition. With this reduced scanning in the camera, it is possible to adjust the camera tube focus to its best condition before returning to normal scanning size.

This reduction of camera scanning amplitude enables the amplifier of a given video bandwidth to render more accurately the fine resolutions of the test pattern, since the given number of elements of this portion of the test pattern are scanned more slowly. Camera focus may therefore be readily adjusted under these conditions, where the video amplifier response no longer limits ability to observe that portion of the resolution wedge corresponding to finest detail.

It might be pointed out here that a 525-line television picture utilizes 525 complete lines of horizontal scanning for each complete vertical picture scan consisting of two interlaced field scans. Of these 525 lines, however, something between 5 and 8 percent of the lines occur during the vertical blanking interval. Therefore, if we consider 7½ percent vertical blanking time, we have 92½ percent of 525 line, or 486 lines of useful picture. This vertical blanking time and also the horizontal blanking time must be taken into consideration when designing and calibrating the resolution wedges for a test pattern.

In the picture monitor circuit it is imperative to have a good d-c insertion circuit which monitors not only the variations in shade from one portion to another of a scene, but also monitors the average brightness level of each scene. We have already discussed the single-ended nature of television signals in that they vary from black level always toward a whiter picture, and not up and down about the black level, as compared with sound modulation signals. When a program is being produced, it is desirable that the pictures be able to fade down toward black between scenes, and that the monitor picture tube go completely dark. As programs are produced either from motion picture film or from a direct pick-up studio, the proper balance must be maintained between all cameras to match this same black level condition.

This d-c insertion may be accomplished by direct coupling of all the circuits to the studio monitor equipment, if it is desired. In this way the d-c components may be controlled. However, direct-coupled amplifiers are not practical where such high gain and such wide band width is required. It is, therefore, customary to regulate the average brightness level of the pictures with regard to the black level of the synchronizing signals. In general, the darkest portion of the scene is set a few percent below the 75 percent or black level mark, so as to give a small tolerance region to insure that the monitor cathode-ray tube will go completely black in between scenes and yet will reproduce the darker portions of the transmitted scene faithfully. Rather than employing direct-coupled amplifiers for transmitting the average brightness level, the same result is accomplished by using a d-c inserting diode in connection with the video amplifier. This d-c inserting diode is connected at the grid of the picture monitor cathode-ray tube or in the grid circuit of the final video amplifier stage, which must then be directly coupled to the cathode-ray tube. Such a diode acts upon the video signals to allow their excursions in one direction only, from a preset voltage. This diode offers extremely low resistance to a tendency of the video signal to send the cathode-ray tube grid bias in a more negative direction than its cut-off value, but offers an extremely high resistance to the tendency of the video signals to go in a direction positive from the grid cut-off value of the cathode-ray tube. In this way, the cathode-ray tube always operates on the useful portion of its grid characteristic, and a low-amplitude video signal simply produces relatively little light, but never a blacker-than-black signal, while a large video signal works always toward the brighter region for increasing video amplitudes.

The picture monitor tube must be observed closely in a television station to see that the scenes being televised are thus properly rendered in their corresponding video signal. On the other hand, the video signals must not be raised to too high a brightness level since they will cause blooming of the final picture monitor tube. In master control equipment the picture monitor units should be balanced carefully with respect to one another, so that any variation of grid control characteristic from monitor tube to monitor tube is compensated by different settings of respective video amplifier contrast controls. It is only in this way that each candidate picture signal may be compared with every other candidate signal in readiness for relaying to the broadcast transmitter to enable its full and efficient operation. The cathode-ray oscillograph waveform monitor units will assist greatly in maintaining this uniformity of picture signals.

Both the picture monitor and the waveform monitor tubes are used in obtaining proper shading adjustments.

12-11. Cathode-ray Oscillograph Monitor—Television video signals are primarily useful when applied to the control grid of the picture-receiving cathode-ray tube for the purpose of varying the intensity of the electron beam to reproduce the lights and shades of the television picture. However, for purposes of monitoring the television signals these same video signals may be applied to the deflection plates of a cathode-ray tube for study. Electrostatic deflection cathode-ray tubes are used for this purpose, since they are adapted to a wide frequency response as compared with the relatively narrow frequency response of a cathode-ray tube using a magnetic-deflection circuit. An instrument using a cathode-ray tube for waveform analysis is called a cathode-ray oscillograph. The video signals applied to the vertical deflection plates deflect the beam upward and downward in accordance with the variations of the video signals. A time-base voltage, usually sawtooth in waveshape, is applied to the horizontal deflecting plates of this cathode-ray tube to spread out the electron beam uniformly with time. As a result, the cathode-ray oscillograph yields a graphic plotting of the video signals vertically against time horizontally. The speed of the time base is adjustable over a wide range and provision is usually made for synchronizing this time base at a sub-multiple of the frequency of the video signals under observation.

Television signals resemble telegraph signals in many ways, although the range of frequency requirements is far greater than that required in normal telegraphy. However, since a television signal is characterized largely by its amplitude variations with time, it is imperative that these signals be studied with a suitable oscillograph. The cathode-ray oscillograph is admirably suited for this purpose, since it has no fundamental limit to its frequency response. However, the cathode-ray tube is only as good as its amplifiers, when it comes to portraying the waveforms in question. Consequently, the cathode-ray oscillograph monitor units must be equipped with high-fidelity video amplifier circuits capable of response to the highest frequencies encountered in the video signals. In some cases it is desirable to provide for a d-c insertion diode in the output circuit of the video amplifier, so that the deflection-plate signals can register both the varying component and the average-level signals of the picture information. Details of the circuits of a portable general-purpose test oscillograph will be given later in the section devoted to Television Test Equipment. However, in a television station setup it is desirable to have a number of specialized waveform monitor oscillograph units, built right into the equipment.

These cathode-ray oscillograph monitor units are to be found in the synchronizing generator, the studio control equipment, the line amplifier monitor circuits, the master control room, the motion-picture camera control circuits, the monitor circuits for the relay receiver for remote pick-up programs, the transmitter room monitor circuits, the off-the-air monitor circuits, and general service and maintenance monitor facilities. In some cases oscillographs may be arranged for switching to cover several of these requirements, but more often it is necessary to have two or three oscillographs for each of these services.

It has been mentioned briefly that the monitor oscillographs are used in connection with shading. In the master-control equipment the cathode-ray oscillograph is used to see that the proper balance is maintained between the picture components and the super-synchronizing components of the composite television signal. While it is possible to monitor the signals at video frequencies, it must also be kept in mind that the characteristics of the transmitter require waveform monitoring since it is not always possible to modulate the transmitter for the whitest white clear down to zero carrier output. The standards specify that good design of transmitters permit modulation down to within 15 percent of peak carrier voltage. Precise monitoring of the amplitude distribution of signals must therefore be made by observation of the r-f envelope at the carrier frequency. Once this has been done and the transmitter characteristics have been determined, it is possible to calibrate the line amplifier video monitor oscillograph in terms of this characteristic. A mechanical vibrating switch may be used for rapid interruption and shorting to ground of the video signals directly coupled from the detected output of the transmitter, giving a reliable artificial "zero" carrier reference level. In this way the master control operator may monitor his outgoing signals more conveniently at video frequency. It is often unsatisfactory to bring the r-f monitor signals directly back into the master control room, since feedback and oscillation of the entire system may result.

In Figure 12-24 is shown a typical test pattern used for broadcasting over a television station. Such a test pattern has been discussed in connection

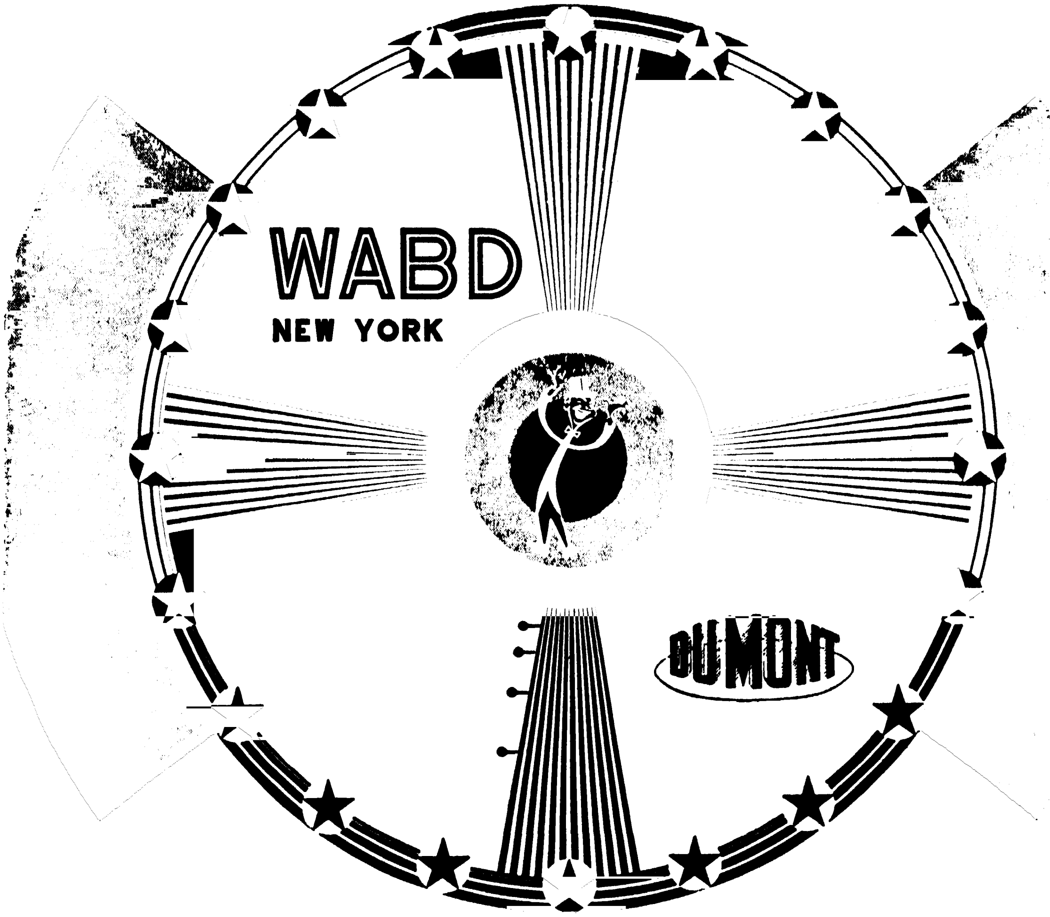

FIG. 12–24. Typical test pattern used in a television system.

with the picture monitor units. Figure 12-26 shows a video-frequency oscillograph waveform corresponding to a similar test pattern. This waveform is photographed from the face of the cathode-ray tube and although it and the ensuing waveform photographs do not correlate with present R.M.A. standards in some respects, the basic principles portrayed remain unchanged. The horizontal scanning frequency for the oscillograph was set at 30 cycles per second and so phased that a complete field of one sixtieth of a second appears in the middle of the photograph. At the bottom of the waveform can be seen the apparently solid line representing the peaks of horizontal synchronizing. If the horizontal scale were expanded sufficiently, the fine structure of the horizontal pulses could be observed, as will be shown in a later photograph. Vertical super-synchronizing pulses may be seen spaced a sixtieth of a second apart for synchronization of successive vertical scanning fields. The apparently solid line next to the bottom represents the black level of the picture. On the calibrated scale at the right of the picture there is a heavy line near the center of the figure, which we shall call 0 percent amplitude. The white portions of the video or picture components do not quite extend to this heavy line. This video waveform has been precalibrated to correspond to the r-f envelope calibration. Ten divisions downward from this dark line may be seen the peaks of synchronizing represented by the bottom apparently solid line. The black-level apparently solid line is shown at about 73 percent on the left-hand portion of the calibrated scale, and at about 71 percent on the right-hand portion of the scale.

This slight clothes-line sag of the signal is probably caused by curvature of the cathode-ray tube to some extent and by deficiency in low-frequency response somewhere in the system. A certain amount of this sag must be expected throughout a television system, since direct-coupled amplifiers are impractical. (Precautions as to constancy of signal level will be treated later in the section on the transmitter and transmitter monitoring.) In this region from 0 to about 14 percent there is no video signal. However, from 14 to

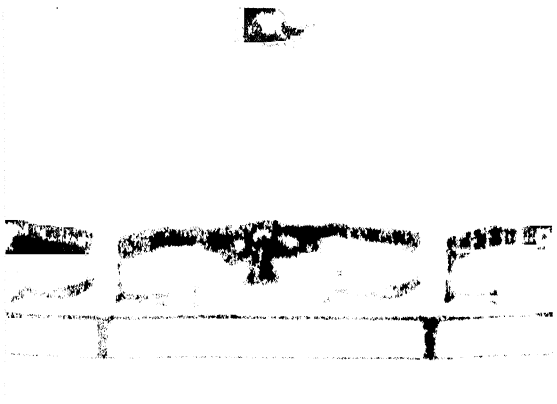

Fig. 12-25. Video frequency oscillograph waveform corresponding to a test pattern, displayed upon a 30 c.p.s. time base to show vertical field intervals.

about 73 percent we have a full range of video signals going all the way from white to black. It will be noticed that the larger concentration of video signals on this pattern is near the white, which would be expected from observing the test pattern of Fig. 12-24. With some careful study it can be seen that the center portion of the oscillograph waveform contains the largest number of excursions toward the black, and this can be correlated with the test pattern where the center portion has the largest proportion of the black. It is interesting to note that many television operators become sufficiently familiar with the oscillograph waveforms so that they may quickly identify the general subject matter of a program simply by observing the oscillograph waveform. A well-known test pattern may be readily identified.

Figure 12-26 shows the oscillograph r-f waveform corresponding to Figure 12-25. This oscillogram was taken from a cathode-ray tube operating directly at a radio carrier frequency of 77.25 mc. The signals were applied to the monitor oscillograph by means of a coaxial cable and a matching network to provide balanced deflection. The cathode-ray oscillograph vertical deflecting plates received the r-f signals directly without any amplifier. The coaxial cable for this purpose was fed by a small pick-up loop placed near the transmission line to the broadcast antenna. Again one can see from this waveform that the transmitter can modulate well within the 15 percent white requirement and has approximately the correct 75 percent black-level pedestal and the 100 percent peaks of synchronizing level. The horizontal scanning rate for this photograph is 30 cycles per second of sawtooth wave form, providing a linear time base. Careful comparison of the r-f waveform of Figure 12-26 with the video frequency waveform of Figure 12-25 shows the similarity of video signals characteristic of the test pattern.

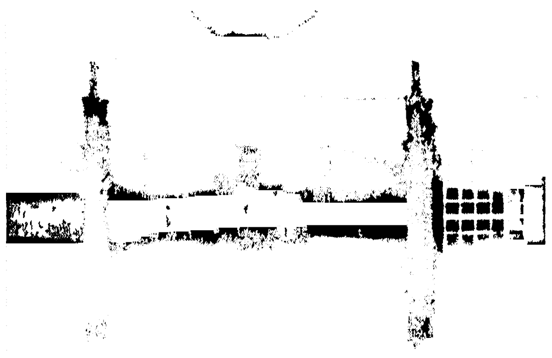

Fig. 12-26. Oscillograph r-f waveform corresponding to a test pattern as shown at video frequency in Figure 12-25.

Figure 12-27 shows an oscillograph video frequency waveform for the test pattern spread to show the line frequency interval rather than the field-frequency interval. Consequently, the horizontal super-synchronizing pulse is shown with its front porch, super-sync and back porch. The horizontal blanking interval is well illustrated. The video components are somewhat different here from those of Figure 12-25, as would be expected, since they represent the horizontal scanning components rather than the vertical scanning components. In order to avoid confusion it should be pointed out that such a photograph as Figure 12-27 is really a large number of separate waveforms superposed upon one another, since a repetition of the waveform for a particular part of a picture cannot take place more often than once every thirtieth of a second, even for a stationary picture.

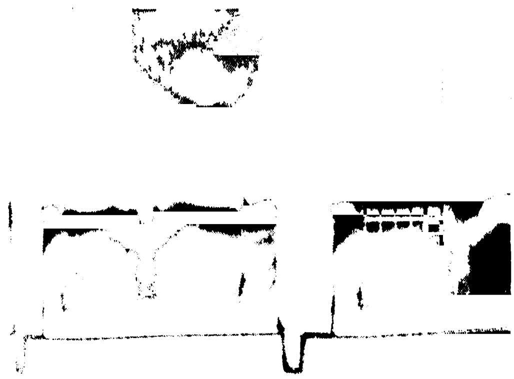

Fig. 12-27. Oscillograph video frequency waveform for test pattern spread to show line frequency interval.

The horizontal scanning rate for Figure 12-27 is one-half of 15,750 cycles per second, or 7875 cycles per second. Thus many lines of television scanning have their respective video waveforms superposed here to give a composite pattern. However, such a cathode-ray tube pattern is very useful in over-all shading of a picture, since the shading controls react upon practically all of the lines of the group. For example, insertion of a sawtooth component at horizontal frequency in the video amplifier would cause Figure 12–27 to have a slanted appearance instead of the relatively flat solid-top portion of the video pattern. This portion would become sloped, for example, from its present left-hand top position downward toward the black, corresponding to a darkened right-hand side of the picture. Likewise, Figure 12–25 illustrates a useful pattern for vertical shading. Consequently, it is desirable to have two monitor oscillograph tubes for each camera chain except for compact portable cameras. Referring back to Figure 12–17 it can be seen that to the left and right of each picture-monitor large cathode-ray tube there are two smaller oscillograph-monitor cathode-ray tubes. Generally, one tube is set up with horizontal scanning frequency on its time base, while the other tube is set up with vertical scanning frequency on its time base. These oscillograph tubes enable the operators to adjust the proper amplitudes within the signal and to adjust the proper shading and time distribution within the signals.

Figure 12–28 shows an oscillograph video frequency waveform for an average picture. Here there is no longer a major portion of white in the picture as shown on Figure 12–25 for the test pattern, but the scene has a general distribution of lights and shadows, as evidenced by the video frequency waveform. This pattern is photographed from the cathode-ray tube, using the vertical scanning interval of one-sixtieth of a second between vertical blanking notches or a linear time base of 30 cycles per second. Figure 12–29 shows an oscillograph r-f waveform for this same average picture.

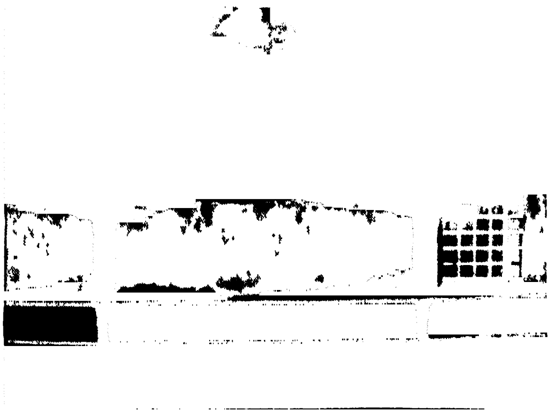

FIG. 12–28. Oscillograph video frequency waveform for for average picture, spread on 30 c.p.s. time base.

The oscillograph monitor tubes may be used to advantage in measuring the characteristics of the sound equipment and in setting the sound levels as well as the video levels.

12–12. Studio Lighting and Operating Techniques—A television studio must be acoustically treated for adequate sound pick-up and must be equipped with far more elaborate lighting facilities than are required for a sound broadcasting studio. It must also provide for realistic scenery and program props. Many of the artificial program effects used in sound broadcasting cannot be counterfeited in television, since the cameras and microphone are sensitive to both sight and sound. A television studio, therefore, requires rather extensive space.

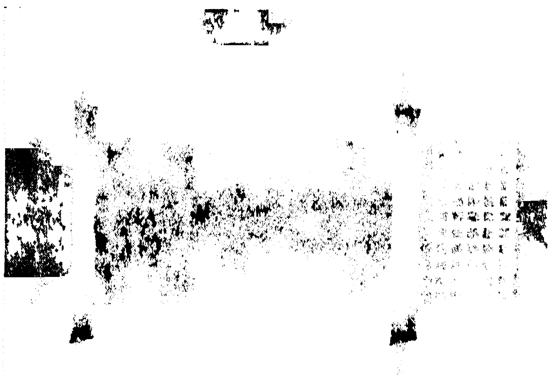

FIG. 12–29. Oscillograph r-f waveform for average picture shown at video frequency in Figure 12–28.

The studio arrangement must allow rapid shifting of the cameras and microphones between several program sets to provide good program continuity. Accordingly, the lighting and the control cabling must be arranged with flexibility. The studio control room generally is arranged somewhat above the floor level of the main studio, so that the control operators may view the studio personnel and program without obstruction.

Since each camera requires wire connection of some twenty to thirty circuits, the camera cables are relatively heavy. They are terminated in suitable plugs on the studio walls. The cables must be flexible, however, to allow motion of the cameras during the program. Various types of dollies are used for television cameras, some employing simple wheels and a supporting structure to allow motion of the camera as a whole, and to allow as well panning of the camera horizontally and vertically. Focusing controls are provided. Figure 12–3 illustrates typical equipment in a television studio. The camera on its dolly can be seen with its electronic viewfinder. The camera man, wearing the intercommunication headphones, is able to receive instructions from the program director for composing the scene required from his camera. A cable-control man frequently works with one or more camera men to assist in the quiet arrangement of the cables to prevent their being kinked or obstructing the free motion of the camera dolly. The sound microphone is operated on a boom and must be kept out of the direct view of the cameras. The sound man is responsible for the adjustment of the microphone and must swing the microphone from scene to scene or else correlate several microphones which may be switched from the control room. All of the studio crew receive instructions by headphone from the intercommunicating system, so that the instructions may be provided even while the studio microphones are picking up the program.

The studio lighting operator is responsible for turning the lights on and off and seeing that the lights are used and moved to the appropriate scenes. Permanent lighting fixtures supported from the ceiling are common for general lighting, although these fixtures are usually arranged so that they may be turned and directed to a limited extent. Bird's-eye incandescent lights and water-cooled mercury arc lights may be used. It is more practical to operate such mercury arc lamps from d.c. to avoid cyclic variations in light output, which are encountered where a-c operation is employed. Careful balancing of several a-c-operated mercury vapor units on several phases of an a-c supply yield reasonably satisfactory operation, although d-c operation is to be preferred. With the incandescent lights, the thermal lag of the filaments is generally sufficient to give a uniform light free of hum where 60-cycle power is employed. The incandescent lighting, however, is generally accompanied by a large amount of heat. Consequently, some form of air conditioning is desirable.

In addition to the ceiling fixtures, it is highly desirable to utilize spotlights and floor lights which may be moved about to provide a good balance of illumination. The required intensity of lighting varies considerably in accordance with the type of pick-up camera tube, and with the nature of the program. The iconoscope cameras require an illumination of the scene of several thousand foot-candles. Orthicon cameras, on the other hand, are more sensitive by approximately five to ten times, and image orthicon cameras require approximately 1/100 the amount of light. In some cases, the orthicon cameras may operate satisfactorily under normal theater or sports arena lighting. However, the nature of the program subject matter determines to a large extent the tolerance requirements of lighting. If the program is very interesting and contains only relatively few objects in the picture, then the lighting is not so demanding, whereas for programs involving much detail and relatively slow movement the lighting requirements become far more important.

The color response in a television system must be considered even for black-and-white transmissions. The characteristics of the pick-up camera tube may be such that certain shades of red may appear as black, while other shades of red may appear as white relative to a gray reference background. Consequently, the choice of scenery and of colors in the scenery is important in the television studio. Obviously, color balance is important where color transmission is involved. In a color studio the fundamental methods of color pick-up require a higher level of lighting than for black-and-white pick-up, since flat spectral sensitivity is desired, and the use of color filters decreases the ultimate light which the optical system finally focuses upon the pick-up tube.

The studio technical crew usually consists of one camera man for each camera, a cable man, a sound man, and a lighting man. In addition to these people, there is a studio program man who correlates their technical activity with the requirements of the actors. Additional personnel may be required for adjustment of the scenery. The number of performers is controlled by the complexity of the show, and will vary from one to twenty-five or more.

Many interesting program effects may be obtained in a studio by the use of dual camera operation and by the use of especially constructed sets in miniature for camera pick-up. In this way, the standard live programs may be combined in an interesting fashion with other background scenes derived from these miniature special sets and from placards or slides. As an example, a studio program may involve camera 1, which picks up a dancing girl on the live stage with a dark background, so that only the girl is apparent as a video signal. Camera 2 is simultaneously focused on a thin-walled aquarium in which seaweed and fish may be seen. In the control room these signals from the two cameras are blended in a video mixing amplifier, with the resulting appearance that the girl is dancing under water among the swimming fish. Many interesting similar combinations may be made where live scenes may be faded into placards and where motion pictures may be combined with still or live subjects in the studio.

Test pattern signals may be generated in the studio by focusing a studio camera directly on a placard version of the test pattern, which is suitably illuminated. Preliminary alignment and adjustment of the studio cameras is accomplished by this means. The use of still pictures suitably illuminated in connection with talks can be combined by proper use of two cameras, one showing the picture, the other showing the lecturer. Many interesting combinations of maps can be made in connection with news presentations. Suitable mirror arrangements may be made whereby pointers or objects may appear to move over the map. The objects may be superposed upon the map optically, so that a single camera sees both pictures at once. In the normal operation of a television station it is desirable to utilize several small studios, some of which may be used for rehearsals of coming programs, while another of the studios is in use for an actual program presentation. A single large studio allows more room for elaborate sets but is not very suited to accommodation of rehearsals and programs simultaneously. The studios must be provided with access to the control room by door and by viewing window. Provision must be made for easy entrance and exit of performers and the stage settings. In addition, a studio audience is sometimes included. A suitable viewing window may be provided to allow the program sponsors or the visiting public to view the show while it is in progress. In many cases, however, the visitors are best accommodated in small theatres where they observe the program upon monitor receivers combining both the sight and sound.

For certain programs it is desirable to set up a studio so that a commentator and his guests may start a program with live action on a stage. Then as the program progresses the commentator and his guests may switch to a film portion illustrating their program, so that during the film presentation from the television film studio the commentator and his guests provide the sound portion of the program from the live studio. In such an event the studio lights are dimmed and a monitor receiver is turned on in the studio so that the commentators may view the pictures from the film on the television monitor and thus synchronize their comments with the action in the film.

In the operation of studio cameras the earth's magnetic field has an influence upon the electron beam in the camera pick-up tube. Therefore, as a camera is moved about to point first in one direction and then in another, the relative intensity of the earth's magnetic field varies, causing a slight shift in the deflection of the entire scanning pattern. Thus it is desirable that the studio camera be equipped with compensating positioning controls, or else that the scanning amplitudes of the camera sweep circuits not be quite great enough to reach the edges of the photo surface. If this photo surface is underscanned a sufficient amount, the motion of the camera in the varying components of the earth's magnetic field will not result in a displacement of the scanning pattern requiring position correction. The scene will shift slightly, but since the camera man is observing the final picture on his electronic view finder, he can nevertheless compose the desired scene properly.

12-13. The Sound Equipment—In a television station the sound equipment is very similar to that in a broadcasting station and therefore will be treated only briefly in this chapter. However, there is not as much freedom in the use of microphones, since it is desirable to keep the sound pick-up units out of the pictures. The sound equipment is some-

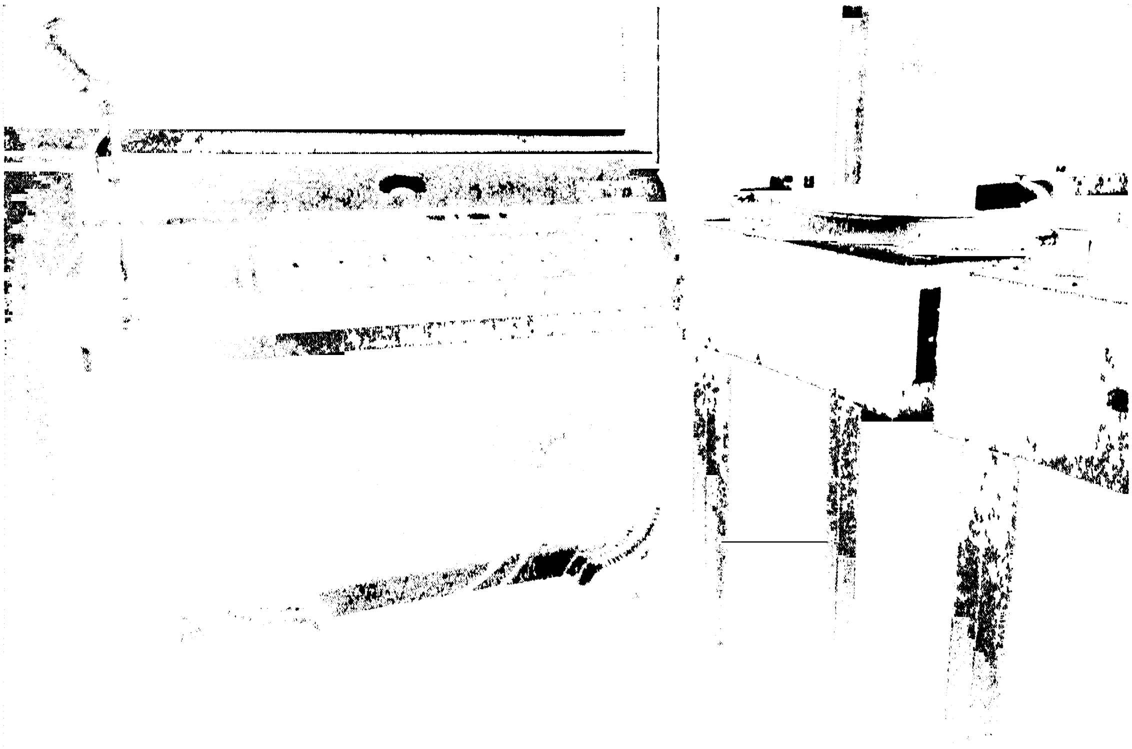

FIG. 12-30. Sound console and two turntables. (Courtesy Western Electric.)

what more complex than that for sound broadcast stations; the control desk must accommodate studio microphones, phono pick-up and motion picture film sound-track pick-ups.

In general, the phonograph equipment is in the studio control room, where the program director and the technical operators may carefully co-ordinate the recorded sound with the live programs. Additional transcription turntables are located in the master control room for provision of musical background programs where close synchronization is not required. The sound-track control circuits are generally located in the master control room or motion picture control room. From the master control room the sound signals are fed to the several monitor positions and to the main sound transmitter. Figure 12–30 shows a Western Electric standard sound control unit with station announcement microphone and pick-up turntables located in the master control room. It is important in the studio that the mechanism for moving the cameras be as quiet as possible. Gyroscopic controls for enforced slow panning are satisfactory if designed for quietness; however, hydraulic operation is preferred. In the studio, intelligent use of one or more microphones and of varying amplifier gain can be co-ordinated with the perspective of the pick-up cameras to produce realistic sight and sound combinations. For example, when a switch is made from a close-up camera to a distant camera, a corresponding change in the sound quality should occur simultaneously with the shift of cameras Suitable frequency response filters may be incorporated, giving the impression of a shift in distance of the observer from the scene.

12–14. The Motion-picture Projector—Both 35-mm and 16-mm films are used for program material in a television station. Entire feature films may be used for full-length program subjects, or short lengths of film may be interspersed with live talent or remote pick-up program material. Where full-length feature films are desired, it is preferable to have two 35-mm motion-picture projectors and two pick-up cameras, in order to facilitate smooth transition from reel to reel for the program, since one film will normally run out in about 20 minutes. Much subject matter is now available on 16-mm film and, therefore, many television stations also are equipped with a pair of 16-mm projectors. Thus, in all, a station may utilize two 35-mm projectors and two 16-mm projectors. These projectors will operate into one or several special motion-picture pick-up television cameras. Many facilities include slide projectors arranged to be utilized with these same pick-up cameras when motion pictures are not being used.

The film camera is somewhat simpler than the studio camera in that it may be relatively fixed in construction and requires no lens of its own and no focusing system, since it is essentially of fixed focus. The lens is actually a part of the projector and once the machine is set up there is no need for any adjustment of focus or direction, as is the case with the studio camera. Figure 12–31 shows a view of a 35-mm television film projector and Figure 12–32 shows the 16 mm film projector. A film iconoscope pick-up camera with its sweep circuits and power supply is shown in Figure 12–33. Figure 12–33a shows the film pick-up unit with cover removed showing the arrangement of individual units.

A television film projector must be equipped with some means of converting the standard motion picture frame rate of 24 pictures per second to a projection such that the television system may transmit 30 frames per second. It is also necessary that this transition in transmitted picture rate not upset the sound track, which must run through at its normal speed of 24 frames per second in order that the pitch of the sound may be natural. This conversion of 24 frames of film picture to 30 frames of television picture may be made in any one of several ways, depending upon the type of camera tube which is employed. The continuous projector is a device wherein the film moves smoothly rather than intermittently through the projector and a

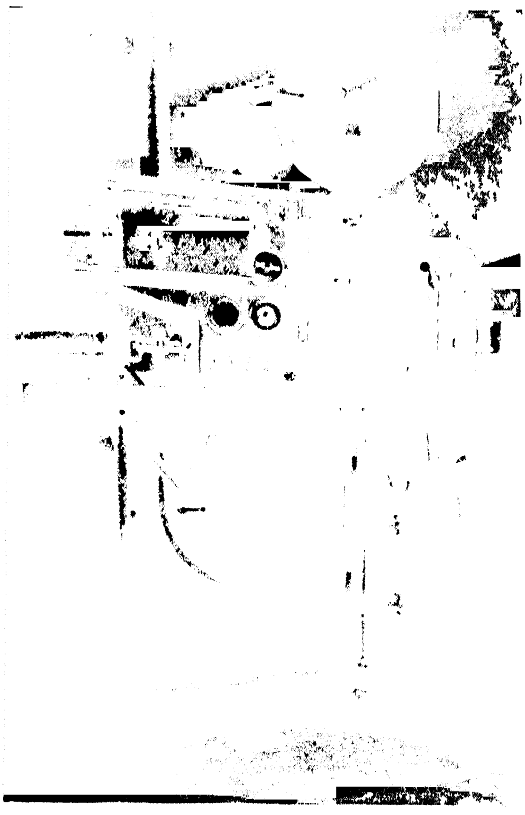

FIG. 12–31. 35 mm. television film projector.

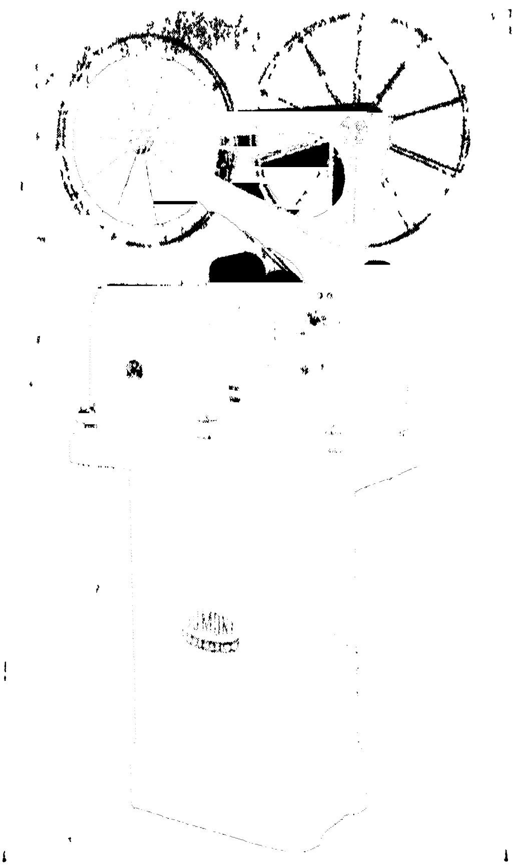

FIG. 12–32. 16 mm. television film projector.

system of prisms or lenses is caused to move along with the film so as to cause the projected pattern to appear to remain stationary. With this type of projector, the scene remains at almost constant illumination level, depending upon the picture content only. Thus, there is no interval of picture-on and picture-off, so that there is no need for adjustment of synchronism between the television system and the number of film frames per second. Accordingly, with such a system the picking up of the film subjects by television is essentially the same as in the studio, where the subject matter is continuously present, ready for scanning. In fact, with a pick-up tube of the dissector type it is necessary to have a continuous type projector which gives uniform light. However, with a tube of the iconoscope type, where the picture mosaic has a certain storage capacity, it is possible to utilize the intermittent action of a standard motion-picture projector, modified only to conform to the television scanning phases. By reference to Figure 12–6 which shows a composite television waveform, we see that the vertical blanking time allows a maximum of 8 percent of $\frac{1}{60}$ of a second between successive fields of television scanning. Use is made of this short interval of vertical blanking in which to project light from a picture frame of the film. The stored energy from this picture frame is left on the mosaic plate of the iconoscope.

Subsequent scanning of this mosaic plate then converts the picture information into the corresponding electrical signals. During this useful picture time, the projector actually is turned off by a special shutter. At the end of this useful vertical field scan interval, there is another vertical blanking interval during which another film picture is projected through this special shutter on to the camera tube mosaic.

In this way we see that 60 flashes of pictures are required per second. The projector mechanism is so designed that three flashes of picture light are obtained through one film frame before the film is pulled down to its next position, and then two more flashes of picture light are obtained through the succeeding film frame. In this way two frames of film produce a total of five flashes of picture light. Two film frames running through the projector at the standard rate of 24 frames per second will, therefore, consume $2 \times \frac{1}{24}$ second or $\frac{1}{12}$ second. These two film frames have been utilized in the interval in which $\frac{5}{60}$ of a second or $\frac{1}{12}$ of a second has been consumed for five flashes of a picture, thus keeping a synchronism between the 60 fields per second of television scanning and the 24 frames per second of film motion. By use of this storage effect, it is possible to allow the projector almost the full use of the picture-scanning interval for pull-down of film, thus making a relatively slow pull-down, which is easy on the film and prevents ripping out of the sprocket holes. If one attempted to pull down the film during the 8 percent of $\frac{1}{60}$ of a second vertical blanking time, serious damage to the film might occur unless a special machine is used.

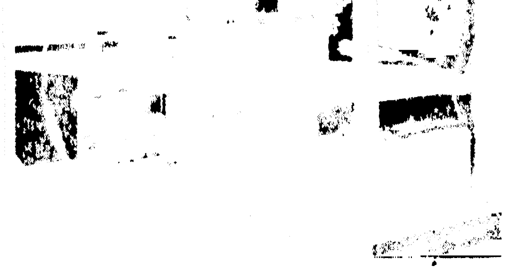

FIG. 12–33. Film pickup unit with cover removed showing arrangement of individual units.

With the large size of the film in a 35-mm machine, it is customary to stagger the pulldown mechanism so that the interval between successive pulldowns is slightly longer and then slightly shorter than the average interval over several cycles, to allow the projection of the 60 flashes per second to occur at uniform rate and yet allow an adequate time for pulldown. However, with 16-mm film the standard uniform intermittent motion at equal intervals between every frame is satisfactory, since the pulldown interval is quite short and the two projections for one film frame and three projections for the second film frame may be phased properly with the standard pulldown mechanism.

A television film projector differs from the standard theater projector in three essential ways. First, the projector requires a special shutter having a very short projection interval and a long opaque interval. Second, the projector may require a staggered intermittent pulldown mechanism having nonuniform intervals between pulldowns. Third, the projector must be driven by a synchronous motor so that it keeps exactly on frequency and exactly at a predetermined and adjustable phase with respect to the synchronizing generator which drives the entire television system. The sound pick-up equipment from the film is standard, since the sound track runs through the mechanism at the normal speed. The sound signals are usually led to the master control sound console, where they are mixed and blended with other program sources.

It is desirable to transmit the d-c component or average lighting level of television film signals as well as the slow or rapid variations of light caused by the scanning process over a given scene. It is impractical to build the video amplifier to cover a range all the way from d.c. to 4 mc, since condenser couplings allow much more simple amplifier design. However, in some motion-picture projector units a photocell is attached, which can record the average light level, and this signal is suitably amplified and connected into the pedestal control circuit to raise or lower the average level of white in the composite outgoing television signal. The monitor oscilloscope and the shading and the level controls for the motion-picture pick-up equipment are frequently located on a control desk as shown in Figure 12-17. It is customary to locate the film projectors in a fireproof room and to project the pictures through openings in a wall into the pick-up camera equipment in a separate room. A line-monitor picture receiver is of great help in the projection room.

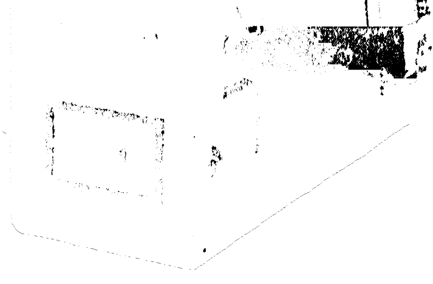

Fig. 12-34. DuMont 5030-A portable synchronizing generator.

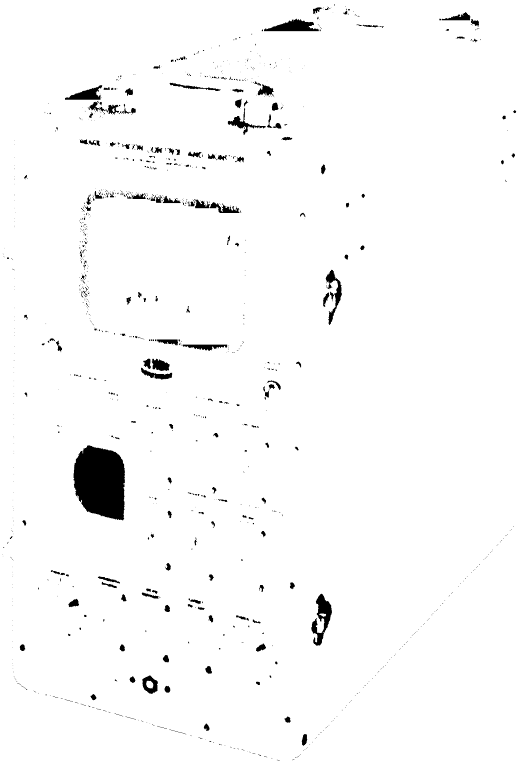

Fig. 12-35. Image orthicon control and monitor unit (Courtesy DuMont.)

12-15. Remote Pick-up Equipment—Equipment used for television pick-up outside of the studio is quite varied depending on the subject matter and the available facilities for setting up such equipment.

Typical fare for remotes is sporting events of all types, spot news, such as parades, fires, etc., and indoor pick-ups, such as concerts, plays and conventions. Camera chain equipment has been designed with sufficient flexibility to meet quite successfully the varying requirements of all types of remote pick-ups.

The heart of the field pick-up equipment is the "mixer-amplifier and monitor." From one to four

FIG. 12–36. Equipment and personnel employed in dual camera chain remote pickup. (Courtesy DuMont.)

composite video signals may be fed into this unit. This is the control point for introducing the special camera effects, such as lap dissolve or fading at predetermined speeds. Manual push-button switching provides for switching, fading, lap dissolve or montages. The output of this unit is fed directly to the video transmission line, thence to the master control at the studio or to a local high-frequency relay transmitter. The several input signals to the "mixer-amplifier and monitor" come from the camera control units, there being one such unit for each camera used. The video signal from the camera and the synchronizing and blanking information from the portable synchronizing generator, Figure 12–34, are both fed to the camera control unit, Figure 12–35. The two monitors on this unit permit the operator to observe both the complete picture and the composite video signal. Manipulation of the various controls provides proper sync level, focus, beam current, target voltage, pedestal level and video gain for the picture being delivered from the camera chain. Additional controls permit the operator to adjust his own picture and signal monitors for optimum operation. Only one synchronizing generator is employed with a multiple camera chain, its output being fed to all of the camera control units.

The equipment so far described is usually located at some convenient point out of the way of the public. The cameras themselves are distributed at strategic locations throughout the area being televised, the video signals being fed back to the camera control units through long cables sometimes several hundred feet in length. These cables also supply a-c and control voltages to the cameras. Figure 12–36 shows the complete equipment and personnel employed in a dual camera chain pick-up. The camera control units for the two cameras are shown at the left. The operator watches both monitors and maintains optimum operation of the cameras at all times. To the right of these units is the "mixer-amplifier and monitor." This operator can switch to either camera control unit, and controls fading, lap dissolves, etc. The picture on this monitor is the one which is sent out over the air. Just behind the technical operators the program director is seated. A complete intercommunicating system makes it possible for him to speak to any of the other personnel. As he is able to see both camera control monitors, he directs the right-hand operator as to which picture is to be used, etc. He can also suggest to the camera men certain desirable shots and camera angles. Figure 12–37 is a block diagram of a complete dual camera chain setup.

Practically all remote cameras in use at the present time employ image orthicon pick-up tubes. This tube is much more sensitive than the iconoscope used in the studio, permitting such pick-ups as night baseball games, boxing and other shows. However, this high sensitivity in the image orthicon is achieved at the expense of the contrast characteristic, often resulting in inferior resolution at low light levels. Section 12–5, Television Cameras, gives a more complete description of the image orthicon tube.

For best operation, the remote pick-up equipment should be fed from a standard public utility power system. However, it is possible to obtain satisfactory results with a well-regulated gasoline-engine-driven, 117-volt 60-cycle generator. In addition to good regulation, it is also necessary that the frequency of the portable generator be highly constant and maintained as closely to 60 cycles as possible. Failure to maintain the power source at 60 cycles may result in receivers slipping out of synchronism since their range of accommodation is rather limited. It is desirable to keep the residual hum in the entire system to a minimum; thus the 60-cycle power frequency should be maintained within reasonable tolerance, since the remote pick-up signals are to be transmitted back to the main transmitter location and radiated through a system involving further 60-cycle hum in the transmitting equipment.

Figure 12–38 shows a typical remote operations vehicle. Everything required for a pick-up, except the 117-volt power supply, is contained in the truck. The roof platform permits setting up two cameras to cover spot news events, while the remainder of the equipment is being operated inside the vehicle. Where the pick-up involves a semi-permanent setup, as at a baseball game, the truck is used simply to transport the equipment and crew to the scene of operations at which point the equipment is unloaded and set up as shown in Figure 12–36.

12–16. Relay Transmitter and Receiver—Since the remote pick-up equipment may be used in widely different locations on short notice, it is desirable to

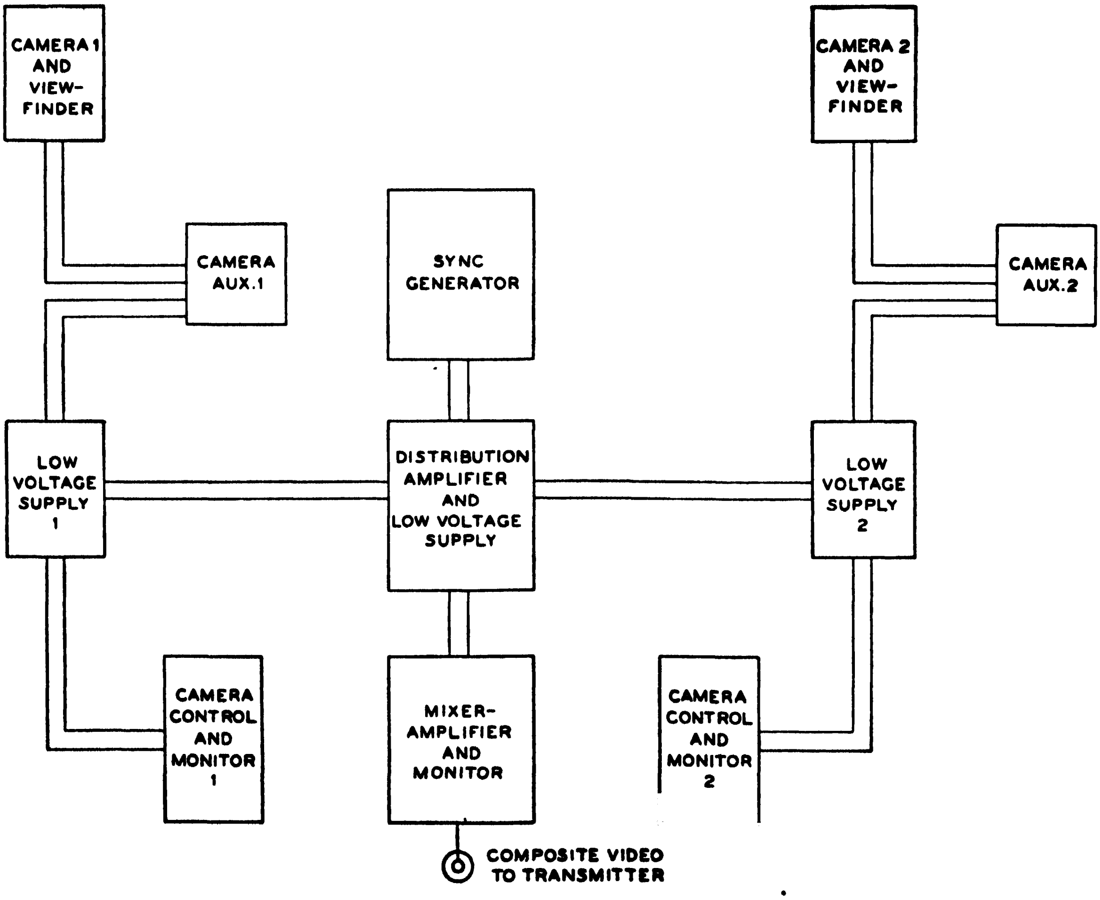
CAMERA 1 AND VIEW-FINDER
CAMERA 2 AND VIEW-FINDER
CAMERA AUX.1
SYNC GENERATOR
CAMERA AUX.2
LOW VOLTAGE SUPPLY 1
DISTRIBUTION AMPLIFIER AND LOW VOLTAGE SUPPLY
LOW VOLTAGE SUPPLY 2
CAMERA CONTROL AND MONITOR 1
MIXER-AMPLIFIER AND MONITOR
CAMERA CONTROL AND MONITOR 2
COMPOSITE VIDEO TO TRANSMITTER

Fig. 12–37. Block diagram of complete dual camera chain setup.

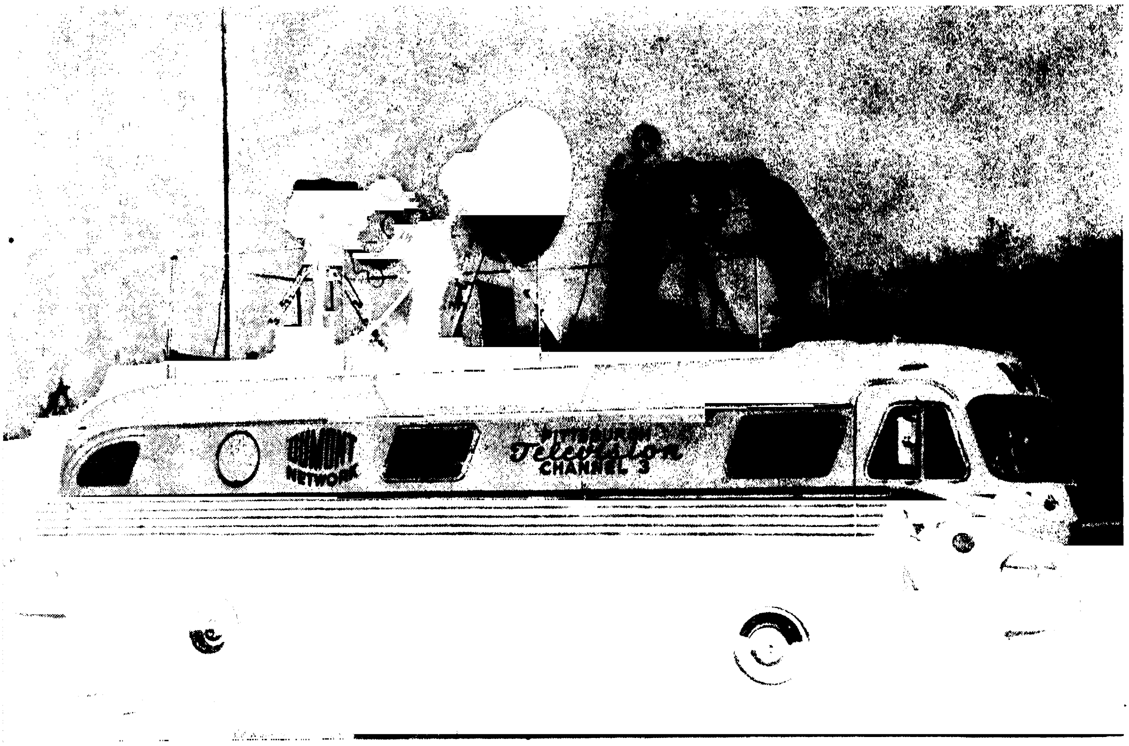

Fig. 12–38. Typical remote operations vehicle.

provide a number of channels whereby the remote pick-up signals can be sent back to the main transmitter. Where a regular schedule of pick-ups is planned, as for example, from a sports arena, it is possible to install coaxial cable facilities or carefully chosen telephone line pairs and to utilize suitable line amplifier terminal equipment. With such facilities, the television signal can be fed from the remote pick-up equipment line amplifier directly into such terminal units and sent back directly to the master control unit at the main transmitter. However, for special-use pick-up or occasional field events, it is desirable to use a wireless relay link.

A wireless relay transmitter such as the one shown in Figure 12–39 may be of relatively low power and, since the transmission is to a specific point, a highly directional antenna may be employed. Such relay transmitters may operate on frequencies of 6800 to 7050 mc. A power of under one watt is generally satisfactory for a distance of several miles, using high-gain antennas which provide better signal-to-noise ratio at both receiving end and transmitting end. This antenna, usually parabolic, gives a power gain of 5000 and may be four or six feet in diameter. It is customary to use a relay transmitter channel approximately 20 mc wide.

The transmitter oscillator, a type 2K26 Klystron, is mounted in the shielded compartment behind the dish. It is frequency modulated by varying the reflector voltage at video frequency. Normal deviation is approximately 8 mc with polarity such that video signal in the white direction causes an increase in transmitter frequency.

The receiver chassis consists of the heterodyne oscillator, the first detector and four i-f stages of the receiver. The heterodyne oscillator is a type 2K26 Klystron, designed for operation in the band 6800 to 7050 mc. This oscillator beats with the incoming frequency to provide (in the crystal first detector) a difference frequency in the i-f bands of 110 to 130 mc. Four stages of i-f amplification follow, and the output of the fourth stage is fed to the receiver control unit which amplifies it for the discriminator circuits. Each of the two discriminator channels contains a limiter circuit, a balancing circuit, and the discriminator circuit proper. The first channel supplies video signal to the video amplifier and the second is used to generate a control voltage for the AFC amplifier.

12–17. Color Television—The transmitting and receiving equipment which is designed to accommodate color television utilizes many of the basic principles of black-and-white systems, but generally it is more complex. A number of laboratories have done extensive work in color television.

FIG. 12–39. Wireless relay transmitter. (Courtesy RCA)

Fundamentally, a black-and-white television system utilizes a single television broadcast channel to reproduce various shades of gray. A color television system must not only reproduce varied intensities of light but must also portray the various hues encountered in nature. The most promising systems for color television employ the three-color method whereby the three primary colors—red, blue, and green—are transmitted in sequence in varying intensities. The three primary colors are then reproduced on the receiver screen so that the human eye, which views the picture, will reconstitute appropriate balances between them, enabling the perception of other intermediate colors. The result is that color television systems generally require three times the bandwidth as compared with black-and-white television or else a sacrifice must be made in geometric resolution. Some promising methods employ multiple interlace principles or a combination of line interlace and dot interlace to conserve bandwidth.

Three basically different methods of color television transmission are under active development employing different rates of switching as to color sequence. These are termed *sequential* color television systems. These three sequential color systems may be briefly designated as *field* sequential color television, *line* sequential color television, and *dot* sequential color television.

The field sequential system switches colors after each vertical scan or field. The line sequential system switches colors after each line or horizontal deflection has taken place. The dot sequential system switches colors after each dot or picture element of the picture is produced. Thus, it can be seen that the field sequential system switches colors at a relatively low rate, for example, at 100 to 200 cycles per second. The line sequential system switches colors at a rate of the horizontal scanning, or perhaps 10,000 to 35,000 times per second. The dot sequential system switches at a rate of reproduction of the individual picture elements which may be at a rate of 3,000,000 to 15,000,000 times per second.

In some systems the following rates have been used. The field sequential system uses a switching rate of 144 vertical scans per second, the colors succeeding one another in a red, blue, and green sequence. The line sequential system uses a switching rate of 15,750 lines per second succeeding one another in a red, green, and blue sequence. The dot sequential system uses either a 3.6 mc or 3.8 mc color keying wave which results in an actual switching rate of approximately 11,000,000 cycles per second, the sequence being red, blue, and then green dots along a given line of the picture

Color television has not yet reached a commercial status because of its greater complexity than black-and-white transmission and because of the practical problem of making color compatible with black-and-white standards.

To reduce flicker, it has been found necessary in experimental work to employ field scanning rates as high as 144 to 180 fields per second for color television of the field sequential type. We have already noted that black-and-white broadcasting employs 60 vertical scans per second (or 50 vertical scans per second, primarily in Europe). Therefore, the vertical and horizontal scanning rates are different in field sequential color than in black-and-white television, presenting a problem in adapting equipment for both color and black-and-white operation.

In line sequential or dot sequential systems of color television, there are also compatibility problems. It may be possible to work out systems such that the standard black-and-white vertical and horizontal scanning rates of 60 and 15,750 per second respectively may also be used for color television. If so, apparatus designed for black-and-white reception can also receive the color transmissions in black-and-white.

There are further problems in color television as compared with black-and-white in addition to those of scanning rates. A color system using a nonsynchronous scanning rate, such as 144 cycles rather than 60 cycles for vertical scanning, requires considerable extra precautions as to filtering of power supplies and shielding of equipment. Color apparatus requires special precautions with respect to registration or superposing of the three primary images. The field sequential system can employ a single cathode-ray tube with rotating color filters, thus minimizing the registry problem. The line sequential and dot sequential systems as frequently utilized employ several colored phosphor surfaces upon which the pictures appear, thus requiring an optical means of providing superposition for viewing of the blended colored pictures.

Some apparatus of the field sequential type employs a single image orthicon camera tube in front of which a multi-segment color filter rotates mechanically at a synchronous rate to provide the field colors at the correct speed. Then color mixing facilities in separate amplifier channels with electronic switching blend the several components to produce colored pictures. Some line sequential systems utilize a single camera with three separate areas excited through suitable color filters. The dot sequential system customarily uses three separate camera tubes on which the three images are registered by the use of a single lens and dichroic mirrors. At the receiving point, three separate cathode-ray tubes can be used for so-called *direct view* by means of the three tubes being suitably placed with respect to dichroic mirrors so that the observer can see the several tubes, some directly through the mirrors, and others by reflection from the surfaces of the mirrors.

There is a practical problem of channel allocation with regard to color television, it being desirable, of course, to utilize 6-mc channels or channels of approximately this width for broadcasting of color pictures in order to make these systems more compatible with black-and-white. Additional spectrum space is needed for either black-and-white or color television, and it is perhaps available for commercial use in the UHF region of the spectrum.

12-18. The Sound Transmitter—The television sound transmitter operates about a carrier frequency located 0.25 mc below the upper edge of the assigned 6-mc television broadcast channel. Figure 12-40 shows a view of a sound transmitter delivering approximately 2½ kw of power. This transmitter delivers its signals through a single coaxial cable to the diplexer, which is described in paragraph 12-22.

The television sound transmitter utilizes frequency modulation. Figure 12-40a shows a view of the F-M exciter unit. Such an exciter unit may use the phase modulation principles or may use a reactance-tube modulator circuit. Crystal control is employed in the transmitter. F-M transmitters are treated in more detail in Chapter 7.

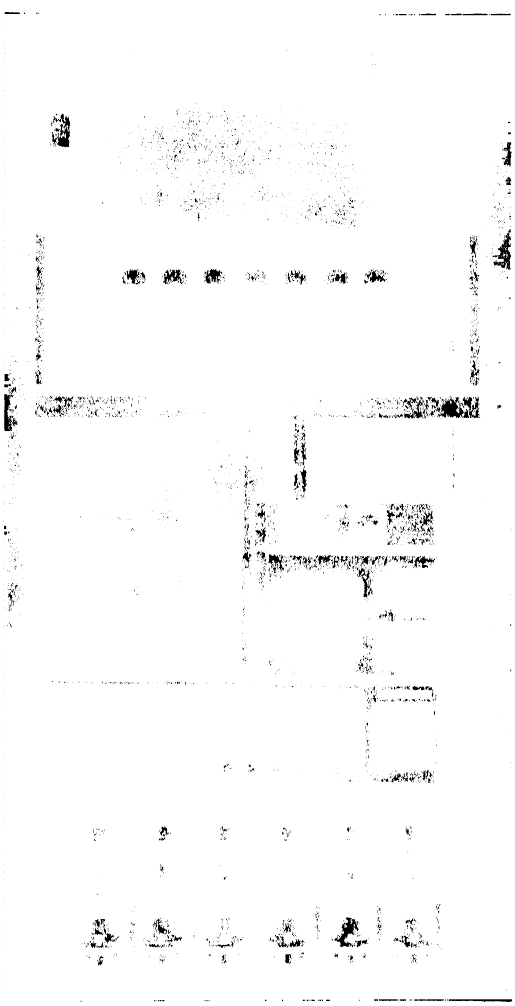

FIG. 12-40. 2.5 kw. television sound transmitter. (Courtesy RCA.)

12-19. The Picture Transmitter—Television picture transmitters employ amplitude modulation and in view of the fact that the video or picture signals contain frequencies all the way from 30 cycles per second up to 4½ million cycles per second, it is desirable that the carrier frequency for the picture transmitter be at least several times the top video frequency of the modulation. It is, therefore, customary for a television picture transmitter to operate on a carrier frequency of 40 mc per second or higher. Each television station is assigned a 6-mc channel. In this 6-mc channel must be transmitted the picture information and the sound information. As already stated, the sound transmitter is located at a frequency 0.25 mc below the upper edge of the 6-mc assigned channel. An additional small frequency band is required below the sound carrier frequency as a guard band between sound and picture. If this guard band is another 0.25 mc that takes 0.50 mc away from the

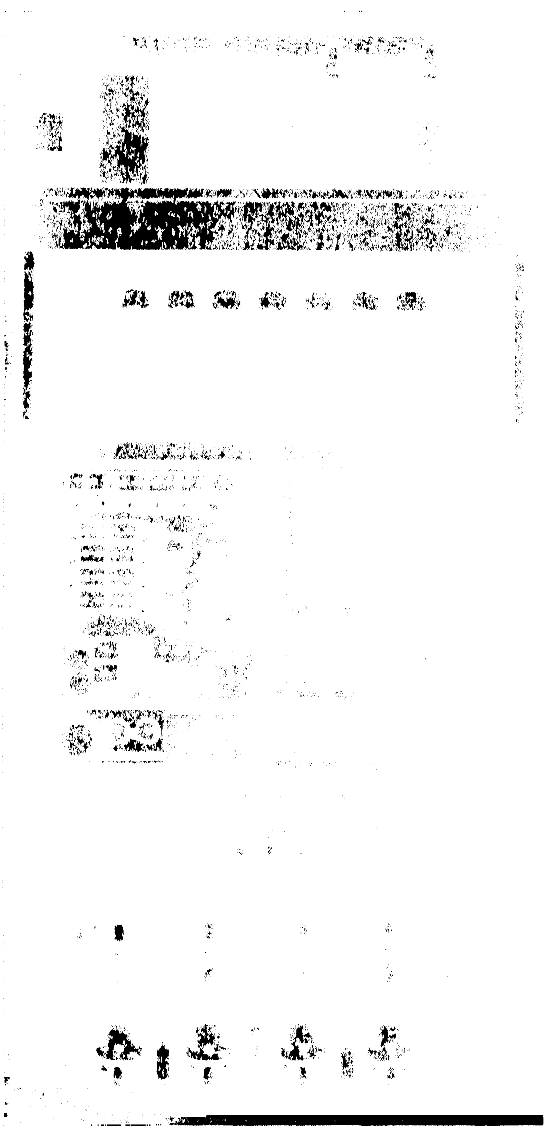

FIG. 12–40A. Television F-M sound exciter and lower power transmitter. (Courtesy DuMont.)

entire 6-mc band and leaves only 5.5 mc for transmission of the picture information.

As stated previously, amplitude modulation is employed for the picture transmission. The top video frequency which may be transmitted by the picture transmitter is about 4.25 mc. In the normal double side-band transmission a bandwidth of the picture alone of 8.5 mc would thus be required, or a value of 4.25 mc each side of the picture carrier frequency. Obviously, an 8.25-mc band is not available within the 6-mc channel. Instead, use is made of vestigial single-side-band transmission. The picture carrier is placed 1.25 mc above the lower edge of the assigned 6-mc channel. This is illustrated in Figure 12–5. A portion of the lower side band of the picture information is transmitted and the entire upper side band is transmitted in the region of 4.5 mc between the picture carrier and the sound carrier, the last quarter megacycle being used as a guard band between picture and sound, the picture information being attenuated away so as not to interfere with the sound signals.

In the 1.25 mc below the picture carrier it is possible to attenuate or reduce the lower side band energy substantially to zero by the time the lower edge of the 6-mc channel is reached. It is imperative that this attenuation of the lower side band be done with considerable care in order that transient or distortion characteristics are not introduced into the picture information. Some forms of transmitters accomplish this attenuation of the lower side band by careful band-pass shaping through several stages of tuned circuits in the coupling between successive amplifiers, beginning at the low-level or low-powered stages. Other forms of transmitters generate the r-f signals with double side band characteristics clear up through the final amplifier stages and then insert a lower side band attenuating filter network in the transmission line between the output tank circuit and the antenna.

Where 4.25-mc modulating signals are applied to a 50-mc carrier, for example, a relatively low *Q* circuit is required in order that equal fidelity may be obtained for both high and low modulating frequencies. This 4.25-mc modulation on a 50-mc carrier is a far lower *Q* requirement than is possible with standard broadcast, where, for example, 5-kc modulation may be employed on a 1-mc carrier. For example, the television ratio is about 4 parts to 50, and in standard broadcasting the ratio is 5 parts to 1000. Thus in television, where wide band pass is required, it is customary to overcouple the circuits so that a wide and flat band pass may be accomplished. In some forms of transmitters it is the practice to utilize only a single modulated amplifier stage wherein the picture modulation is accomplished in the final or output stage.

A diagram illustrating a television picture transmitter is shown in Fig. 12–41. Figure 12–42 shows the complete video transmitter of WTTG, Washington. Cabinets to the left contain the crystal oscillator stages and the low-powered amplifier stages in which modulation occurs. The larger cabinets to the right contain the power amplifier stages, the power supplies and the output stages. A crystal oscillator stage operating at the relatively low frequency of 5 to 10 mc is fed through several doubling or tripling stages to generate the station picture carrier frequency. This carrier-frequency energy is then applied to the grids of the first modulated stage of the transmitter. Figure 12–43 shows a video driver stage, the r-f exciter link, and the associated power supplies. The video signals are supplied from the master control room by means of a coaxial cable fed from the line amplifier or a sync

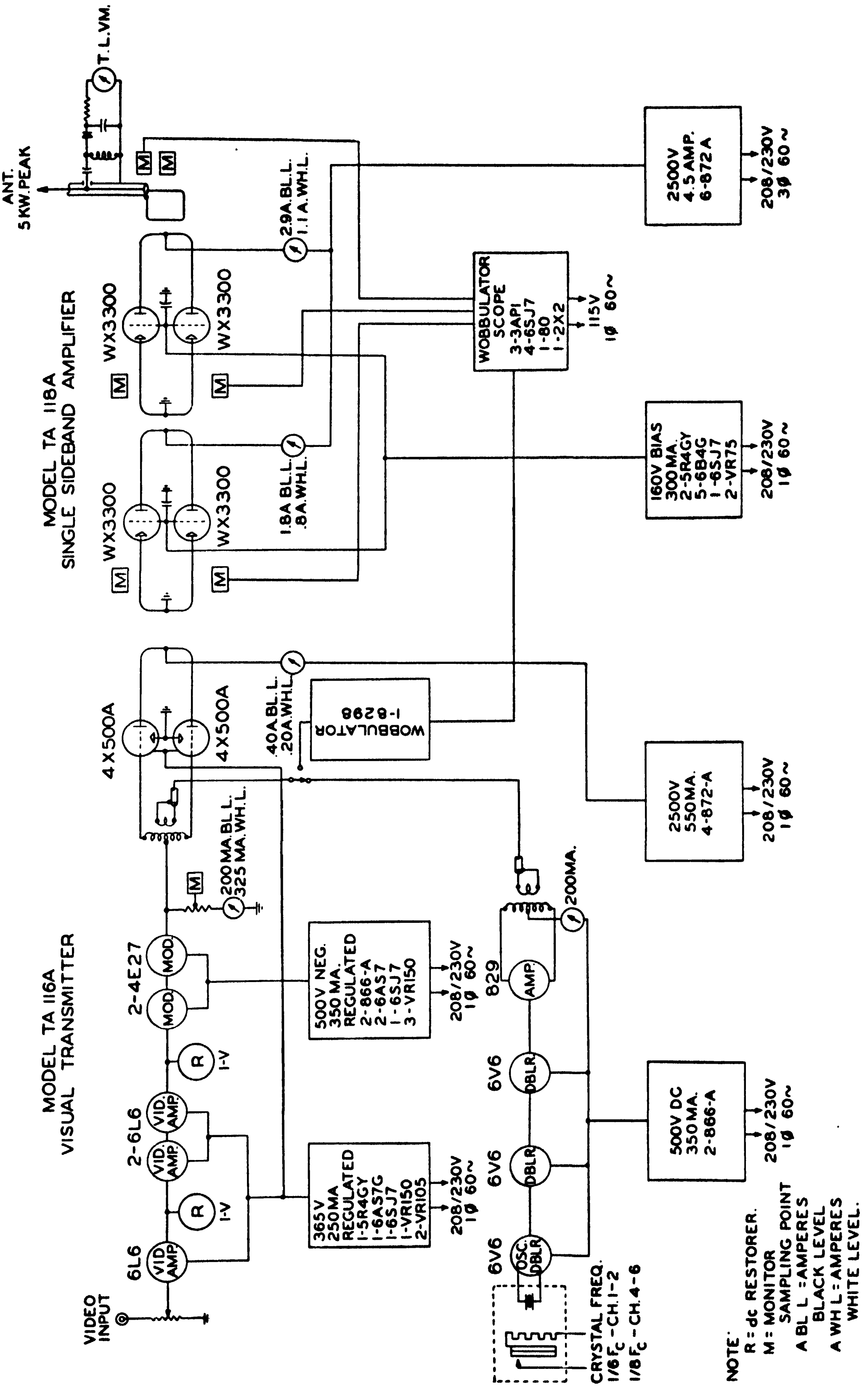

FIG. 12–41. Block diagram illustrating television picture transmitter. (Courtesy DuMont.)

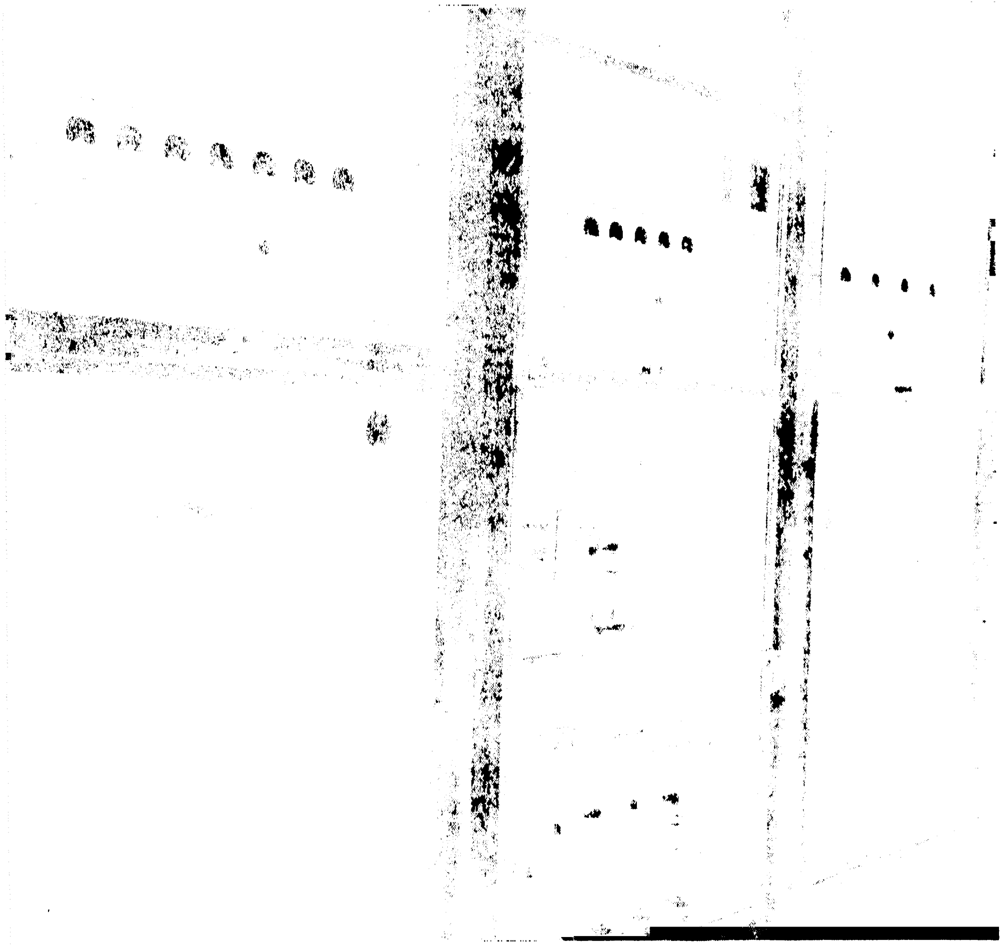

FIG. 12–42. Video transmitter of television station WTTG, Washington showing 5-kw. amplifier, low-powered stage, and heavy duty power supply for 5-kw. stage.

stretcher. On this coaxial cable appear the television signals consisting of video components and synchronizing components, as previously described and as illustrated in Figure 12–6.

The transmitter shown here is modulated at low level, and side-band filtering is accomplished by band shaping in several successive amplifier stages. Units shown in Figure 12–44 illustrate the exciter and r-f amplifier which takes the video signals from the coaxial cable line and brings them to a sufficient level, so that they may be used to modulate the grid circuit of the r-f amplifier. A constant amount of carrier frequency voltage is coupled inductively into the grid tank circuit of the first modulated stage. This grid tank circuit is then driven at video-frequency voltage up and down to such an amount that, on peaks of synchronizing, the r-f tubes are driven to nearly zero bias whereas, on the peaks of white, they are driven to nearly complete cutoff.

The television system is single ended as to carrier modulation or works entirely from the blacker-than-black peak of synchronizing level down through black and toward white, which is minimum carrier amplitude. Thus it is necessary that the video modulating amplifier have some means for inserting the d-c components. This is accomplished by direct coupling between the video amplifier stage and the grid tank circuit of this first r-f modulated amplifier stage. In the grid circuit on this last video amplifier stage a d-c leveling diode is connected so that the video signals operate from the fixed level of the synchronizing peaks. This means of maintaining the d-c level of a big transmitter is illustrated in the schematic diagram of Figure 12–45.

Figure 12–44 shows a 500-watt exciter unit consisting of a crystal-controlled exciter, power supplies, modulator, and modulated amplifier. Note the video sweep generator in the center of the transmitter frame for use in testing while obtaining the pass band characteristics. Figure 12–46 shows the linear amplifier and the final output stage of the

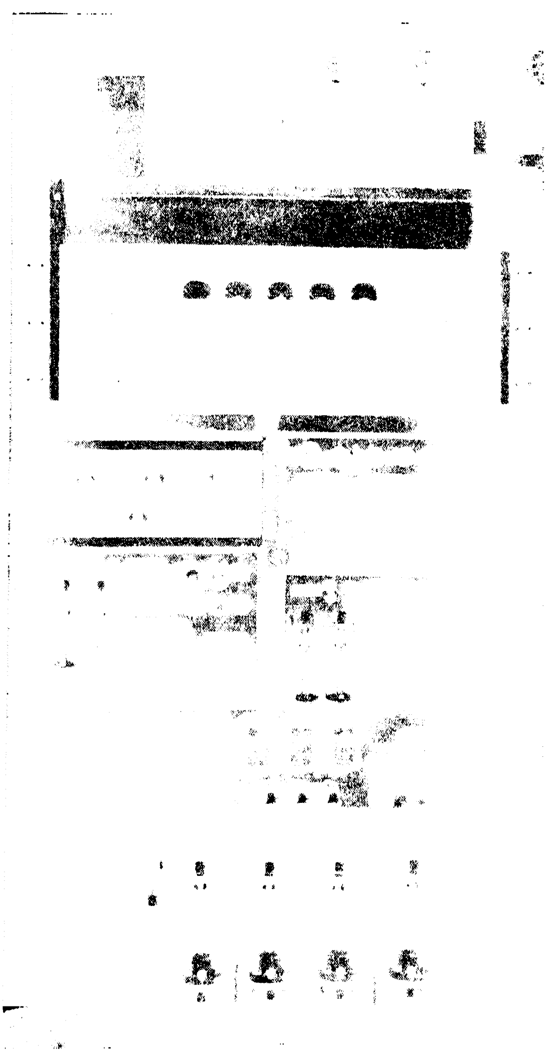

FIG. 12–43. Video driver stage, the r-f exciter link and associated power supplies. (Courtesy DuMont.)

picture transmitter. Both of these stages are air cooled. The intermediate power amplifier stage employs a push-pull pair of WX3300 tubes and the output stage employs a pair of WX3300 tubes.

The transmitter of station WTTG shown in Figure 12–42 operates on the channel from 76 to 82 mc, and use is made of cathode drive of the output stages and also the intermediate stages, wherein the grids are by-passed directly to ground. The grounded grid circuit used gives a very low input impedance which provides the necessary wideband circuit loading without wasting power. The push-pull output of the final stage is converted to single-ended connection (necessary for the coaxial transmission line to the antenna) by passage through a balanced-to-unbalanced converter (bazooka) as shown in Figure 12–46. Figure 12–47 illustrates a 3-phase power supply for the video transmitter amplifiers. This supply delivers 5 amp at 3000 volts, although the voltage can be varied by the motor driven variac control.

Another transmitter, Figure 12–48, is of radically different design from that described above and employs narrow-band multipliers up to the final stage and employs high-level modulation at the grid of the final stage. The undesired portion of the lower side band is removed by a high-level filter in the antenna transmission line instead of band-shaping circuits.

The final stage employs a water-cooled double tetrode, type 8D21, of unusual design, shown in Figure 12–49. Distilled water, supplied at a rate of about 1.7 gallons per minute, is forced through the plate, as well as through both control and screen grids, which are hollow. Water is also applied to the filament seals. This thorough-going

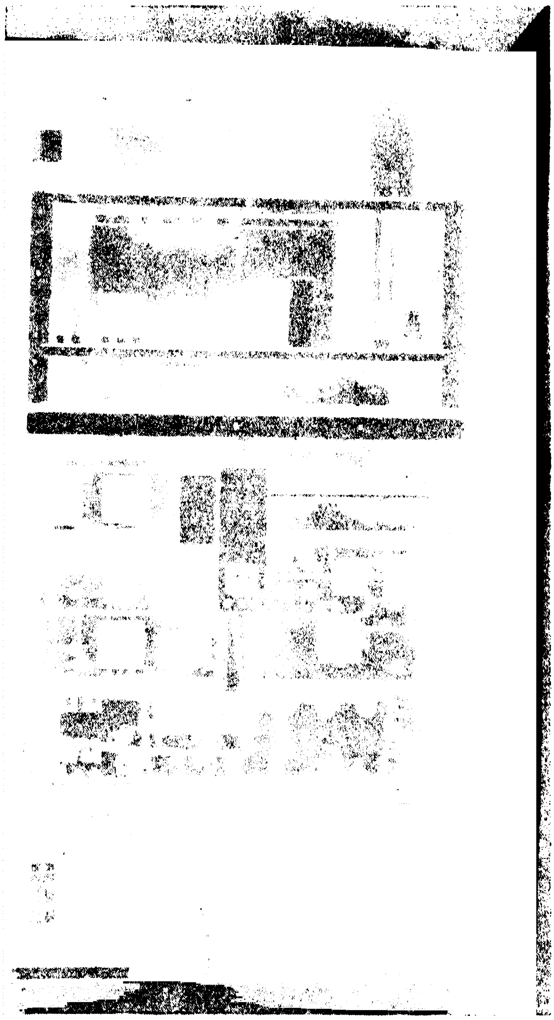

FIG. 12–44. 500-watt video exciter unit consisting of crystal controlled exciter, power supplies, modulator, and modulated amplifier. (Courtesy DuMont.)

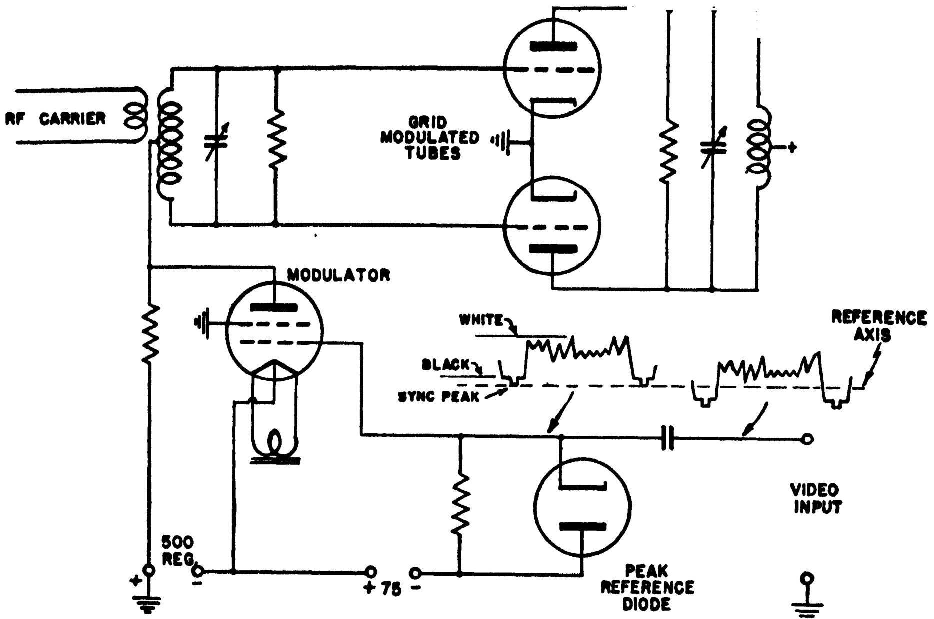

FIG. 12–45. Schematic showing means of maintaining d-c level of large transmitter.

cooling system permits the tube to be operated at the very high plate dissipation of 370 watts per square centimeter of anode surface.

The vestigial side band filter is essentially three filter sections constructed of coaxial line. Two of the sections are *m*-derived units, one for passing a portion of the lower side band energy to a water-cooled terminating resistor, the other for sharpening the cutoff at the edge of the upper side band. The third filter section is a notch filter for removing any picture-signal energy at the frequency of the sound channel of the next lower television channel. The notch filter also dissipates its energy in a water-cooled resistor. All elements of the side band filter are constructed of 3⅛-inch, 72-ohm coaxial line.

12–20. Transmitter Monitor Facilities—Throughout the picture transmitter, use is made of conveniently located pick-off diodes, beginning at the first modulated r-f stage and going up through the intermediate power amplifier stages and the final output stage to the antenna circuit. These diodes pick off a small amount of energy from these stages and rectify the envelope of the signal and deliver the test signals as video frequencies over coaxial cables to the main monitor unit in the transmitter room.

Figure 12–50 shows a view of the transmitter monitor desk, illustrating the monitor picture tube and the monitor oscillograph with facilities for switching of these to appropriate circuits throughout the transmitter so as to view the pictures as they progress through the transmitter. Such monitor facilities assist greatly in tuning up the transmitter and in determining that the stages remain in proper tune during normal operation. It is necessary that a good picture be available at each monitor stage in order that the over-all fidelity of the transmitter be maintained. For example, the front porch and the peaks of synchronizing and the back porch of the synchronizing waveform must be carefully maintained. If, however, some one stage of the transmitter is so tuned that it accentuates certain frequencies, these square waveforms may have sharp tails produced by this erroneous tuning. Once these tails have been introduced in one part of the transmitter they may become saturated in later stages, and it is thus impossible to equalize certain signals back to the proper waveshape in the final radiation. These successive monitor diodes, therefore, are quite important in the initial adjustment of the transmitter and in observing the normal operation.

In the final tank circuit of the power output stage, it is possible to incorporate a cathode-ray tube which is operated directly at radio frequency. A small pick-up loop is coupled to the output tank circuit and is connected by coaxial cable to a special cathode-ray oscillograph having a cathode-ray tube with very low capacitance deflection plates, such as Du Mont type 287, Figure 12–51.

Precautions must be taken in installing the r-f monitor oscilloscope: the circuits should be well neutralized, and the r-f signals should introduce only vertical deflection without horizontal components in the cathode-ray tube. The horizontal deflection circuits of the cathode-ray tube are connected to standard sweep circuits which may be synchronized internally to the 60-cycle power main for most of the observation, since the 60-cycle envelope of the

FIG. 12–46. Second linear amplifier and final output stage of television picture 5-kw transmitter. (Courtesy DuMont)

field frequency-component is probably the most generally observed waveform. However, it is desirable also to provide for time base synchronization with the video frequency signals, so that observation may be made of the picture horizontal frequency envelope. Figures 12–52 through 12–58 illustrate several r-f envelope pictures photographed from the face of an r-f monitor oscilloscope such as shown in Figure 12–51. These pictures represent the principles of a television system although some were taken with the 500-kc verticle sync pulse. Only by observation of this r-f monitor pattern on the output stage of the transmitter is it possible to determine without doubt that the transmitter is modulating clear down to zero carrier on the peaks of white. Some transmitter designs will allow more complete modulation to zero carrier amplitude on the white than others, depending upon the degree to which it is possible to neutralize the amplifier push-pull stages. It can be seen from Figure 12–56 or Figure 12–58 that certain types of picture signals are able to modulate this transmitter well within the 15 percent carrier required by standard number 13.

A television signal may be largely black or largely white, depending upon the particular scene, and thus the average radiated carrier energy is not constant, as in the case of sound broadcasting. It is therefore customary to rate television transmitters on their peak power, which is maintained constant on the peaks of picture synchronizing. The r-f monitor oscilloscope may be utilized for determining the constancy of peak output power once it has been suitably calibrated and provided its coupling is not changed. However, another means must be employed in making an initial calibration of the power output. Usually the transmitter is set up on the dummy load and the peak power determined as in Section 12–21. Another method of checking modulation is that in which the diode is intermittently

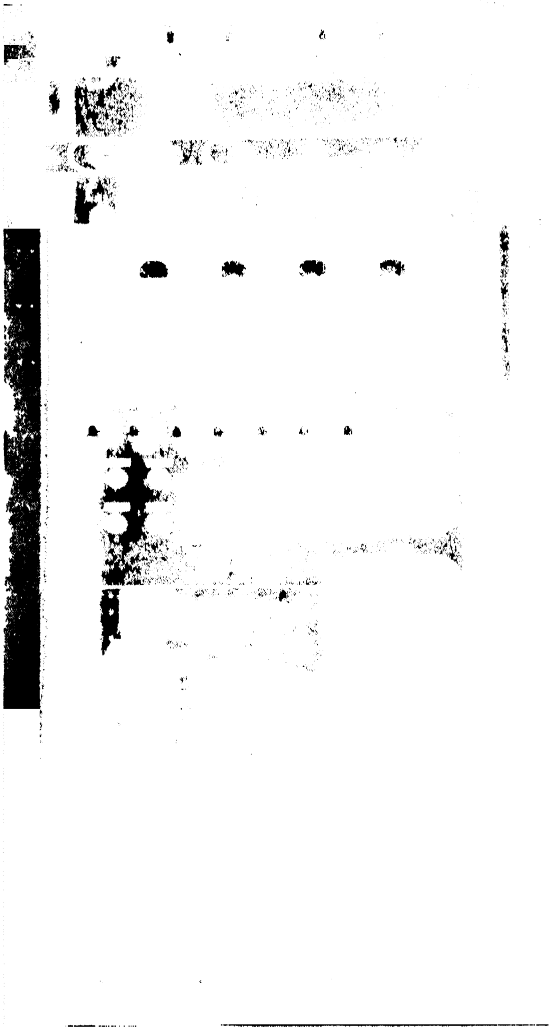

FIG. 12–47. Three-phase power supply for video transmitter. (Courtesy DuMont)

FIG. 12–48. RCA television transmitter.

shorted out, giving a zero reference level on the rectified video signal.

An ideal receiver is used to monitor the transmitter at all times. This receiver has its pass-band and transient response standardized by R.M A.

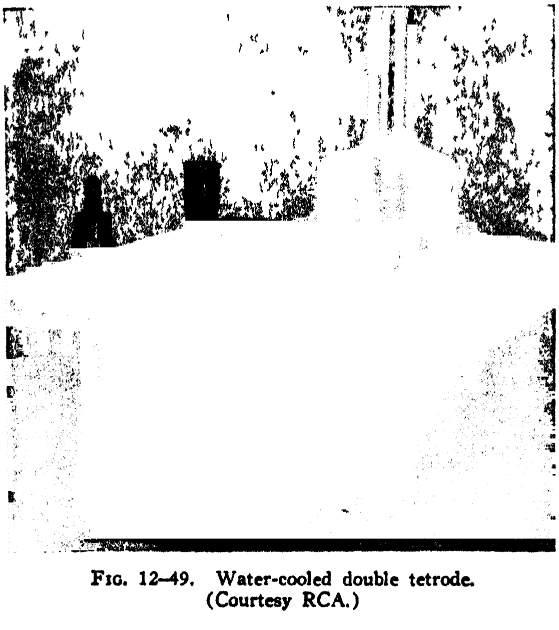

FIG. 12–49. Water-cooled double tetrode. (Courtesy RCA.)

12–21. Picture Transmitter Power Measurements—The direct method of measuring the power of a television transmitter consists of using a dummy load of the same characteristic impedance as the transmission line and measuring the temperature rise and number of gallons per minute of the cooling water flowing along the dummy load resistor. The peak power of the transmitter is obtained by measuring the average power on a black picture and multiplying this figure by 1.68 to get the peak power The following formulas show how the average power and peak power are obtained.

$$\text{average } P = 0.263(T_{\text{out}} - T_{\text{in}})G/\text{min.}$$

$$\text{peak } P = \text{average } P \times 1.68$$

where P = power in kilowatts
T = temperature in degrees centigrade
G = gallons of water

The indirect method of power determination may be applied to television transmitters. For example, the input volts and input amperes to the final power amplifier stage may be read directly from the meters. A conversion efficiency varies from 20 to 50 percent for this final stage.

However, it is desirable that some method other than the indirect one be utilized for television transmitters. In a specific case, one 72-ohm coaxial transmission line takes the signal to the antenna.

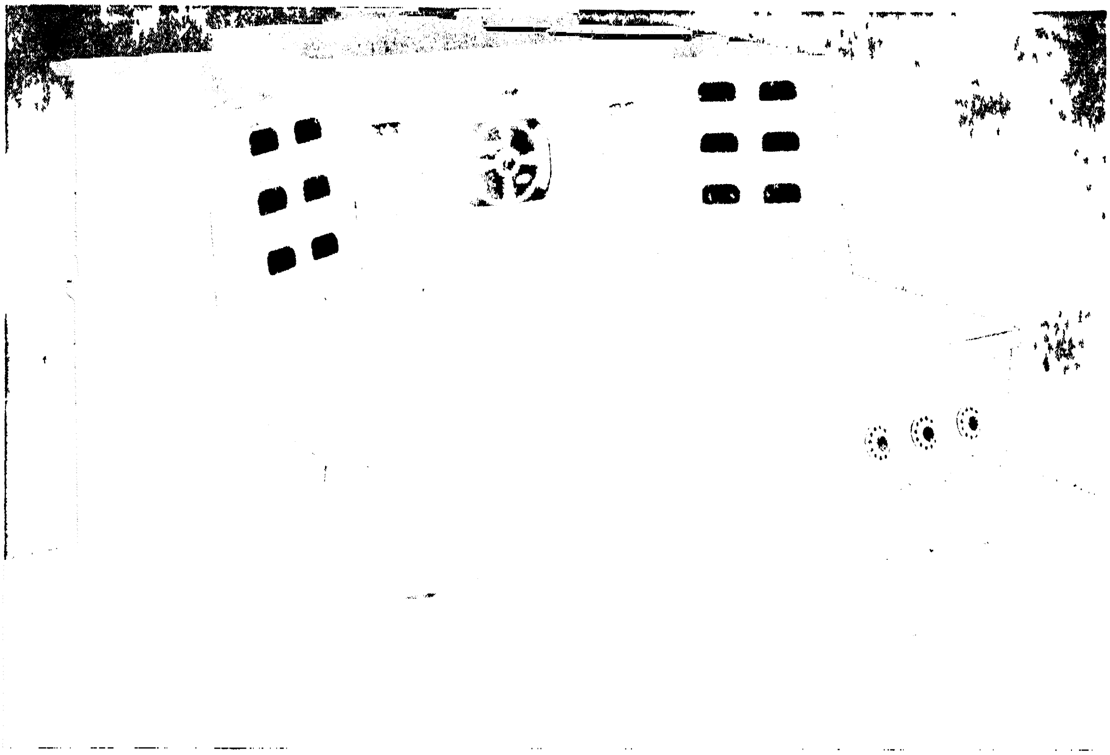

Fig 12–50 Transmitter monitor desk (Courtesy DuMont)

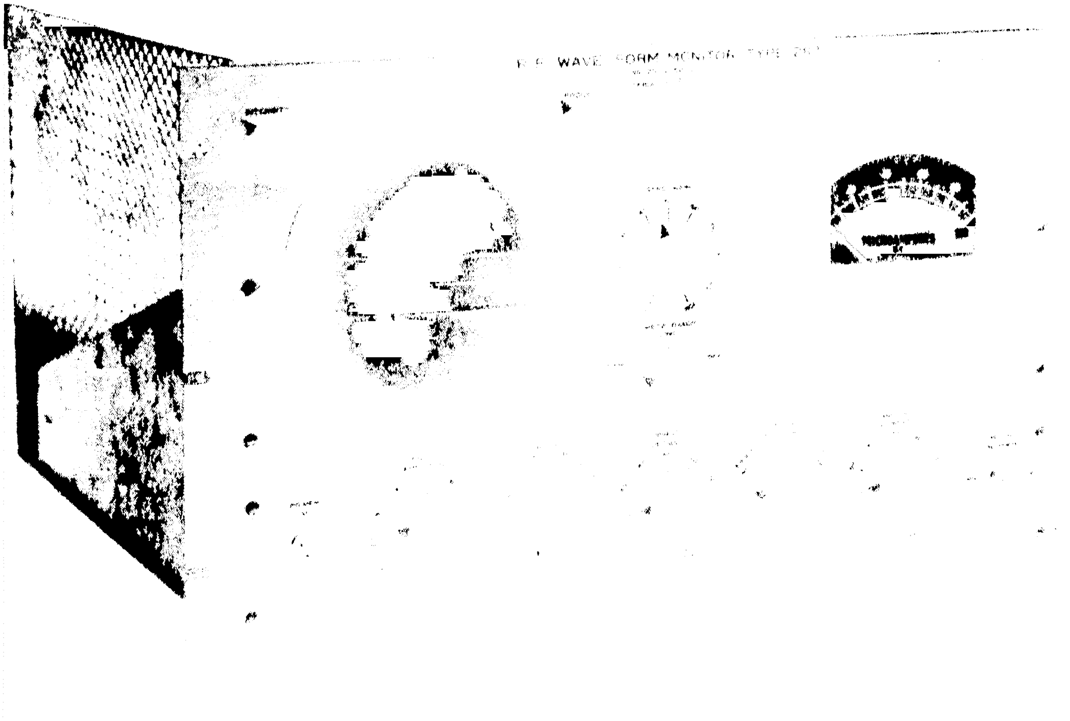

Fig 12–51 R-f waveform monitor (Courtesy DuMont.)

Power measurements may be made on the coaxial transmission line if suitable precautions have been taken to determine that no standing waves of appreciable magnitude exist on the transmission line. Somewhere along the transmission line a simple low-capacitance diode is connected directly to the center conductor. This diode then detects the peak r-f signal which is transmitted over this cable. A filter circuit of long time constant is employed in the output of this diode and thus the diode becomes a peak-reading voltmeter as shown in the schematic circuit of Figure 12-59. The television signal has peak power on the picture synchronizing peaks. The d-c reading may be observed at some remote point on the control panel. The table of Figure 12-60 illustrates typical readings, including the final plate current and final plate voltage. These values may be compared with the photographs of the specific waveforms of the picture being transmitted.

In the general case, the following definitions and illustrative symbols may be utilized in computing the average effective radiated power of a television picture transmitter.

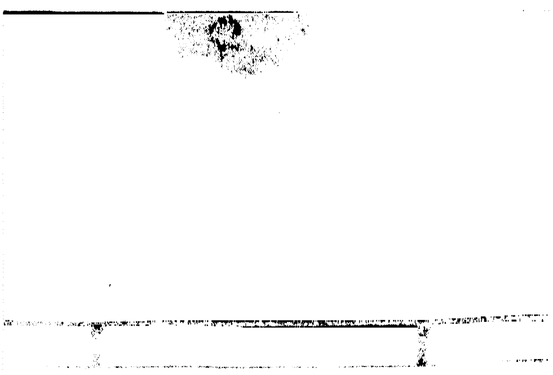

FIG. 12-52. Oscillograph pattern showing video frequency waveform for a black picture (super synchronizing only).

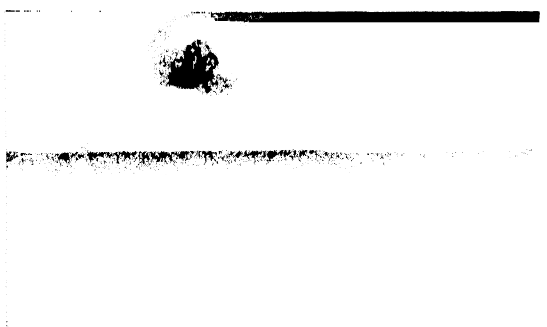

FIG. 12-53. R-f waveform of picture transmitter for black video signal shown in Figure 12-52.

FIG. 12-54. Oscillograph video frequency waveform for a picture consisting of uniform gray background.

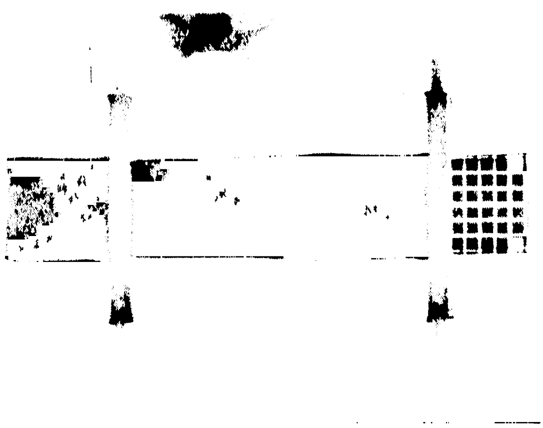

FIG. 12-55. R-f waveform of television transmitter output for gray background picture illustrated in Figure 12-54.

P_1 = Effective radiated power on peaks of synchronizing.

P_2 = Average radiated power for a black picture.

P_3 = Average radiated power for a completely white picture.

F_{TL} = Efficiency of the transmission line.

A_{PG} = Antenna power gain.

P_4 = Power delivered by transmitter to transmission line on peaks of synchronizing.

E_1 = Peak voltage indicated by diodes on transmission line.

E_2 = rms value of r-f voltage on transmission line on peaks of sync.

Z_{TL} = Impedance of transmission line.

I_P = Plate current in final r-f stage.

E_P = Plate voltage in final r-f stage.

P_5 = Plate input watts.

Then

$$E_2 = 0.707E_1$$

$$Z_{TL} = 72 \text{ ohms}$$

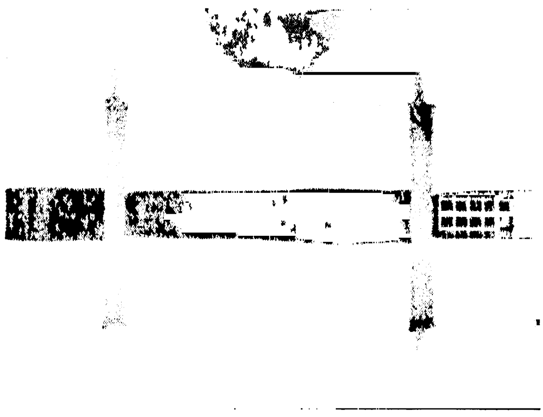

Fig. 12–56. R-f envelope for television picture which is just a white uniform background.

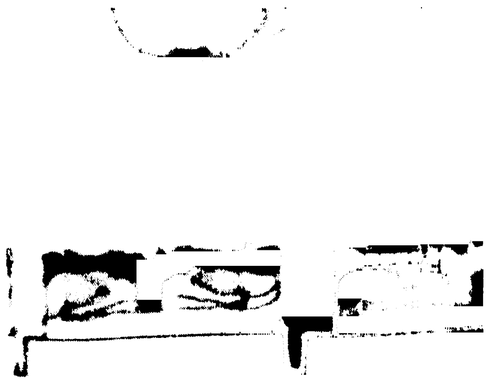

Fig. 12–57 Video waveform for a test pattern, on a time base showing two horizontal line intervals.

For example, if we have a delivered peak d-c voltage of $E_1 = 750$ volts, we have a peak r-f voltage of 750 volts across 72 ohms This corresponds to an rms value of r-f voltage of $E_2 = 0.707\ E_1$, or r-f voltage on synchronizing peaks of $E_2 = 530$ rms volts across 72 ohms. Thus the power delivered to the transmission line on the peaks of synchronizing is

$$P_4 = \frac{(E_2)^2}{Z_{TL}} = (530)^2 \div 72 = 3900 \text{ watts peak}$$

This rms value of delivered power on the peaks of synchronizing is delivered by the transmitter to the transmission line. However, we have a loss in the transmission line, which is approximately 150 feet long, of approximately 5 percent in power absorbed by the line Therefore, there is delivered to the antenna system $F_{TL} \times P_4$ or 0.95×3.90 kw $= 3.70$ kw. The antenna array is a three-section batwing super turnstile equivalent to six simple turnstile bays giving an omnidirectional coverage as described in a succeeding paragraph. The array has a power gain of $A_{PG} = 4$ and thus the effective radiated power from the antenna on peaks of synchronizing is

$$P_1 = A_{PG} \times F_{TL} \times P_4 \text{ or } 4 \times 3.70 \text{ kw} = 14.8 \text{ kw}$$

To determine the average television power we must consider carefully the composite television waveform of Figure 12–6. The average power radiated depends on the particular scene being transmitted. For example, if the picture is faded down completely to black, the peak power will be the same as though the picture were completely white, but the average power will be widely different for these two conditions, as can be seen by the large variation in input power or input current to the final stage of the television transmitter shown in the table of Figure 12–60. The photographs of the r-f envelope for the pictures in Figures 12–53 and 12–56 illustrate the conditions for a black picture and a picture which is almost completely white respectively. In Figure 12–52 can be seen a photo of the video frequency waveform for a picture which is completely black. In considering this table it would be well to refer back to Figures 12–57 and 12–58 which deal with video and r-f waveforms for test pattern and which were discussed above.

For the condition when the television program is faded to complete black, the power calculation may be made as follows. The front porch and back porch levels of the synchronizing signal correspond to 75 percent of the transmitter peak carrier voltage as seen in Figure 12–6. When the picture is faded to black, the entire video signals are also at this level. Only the horizontal and vertical synchronizing signals project upward from this level to 100 percent carrier voltage amplitude and thus tend to raise the average voltage above the 75 per cent level. The horizontal synchronizing pulse lasts for 8 percent of the time of a horizontal line. During the vertical blanking interval the vertical synchro-

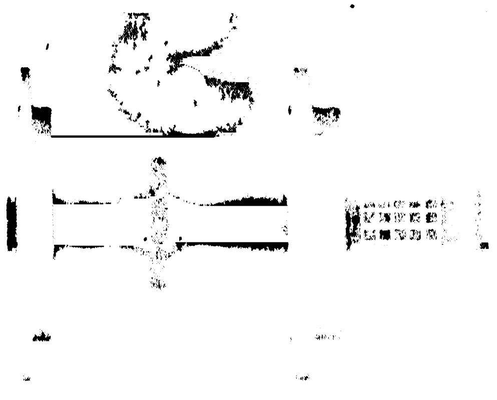

Fig. 12–58. Composite r-f waveform for test pattern showing that synchonizing peaks remain at the same amplitude as with gray or black steady level.

nizing information consists of equalizing pulses and vertical synchronizing signals. Two equalizing pulses are equivalent in energy to one horizontal synchronizing pulse. It is, therefore, necessary only to consider the additional energy included in the vertical super-synchronizing long-duration pulses of which there are six half-line pulses during each vertical blanking interval; hence, six occur during each television field interval. Thus these vertical pulses further raise the average voltage level on a black scene.

The value E_2 equals the rms value of r-f voltage on transmission line on peaks of sync and corresponds to the 100 percent voltage amplitude. Then if E_3 equals rms value of the average radio-frequency voltage for a black picture, we have:

$$E_3 = 0.75E_2 + 0.08 \times 0.25E_2 \text{ (from the horizontal sync)} + \frac{3}{262.5} \times (1.00 - 0.08 - 2 \times 0.07) \times 0.25E_2 \text{ (from the vertical sync)}$$

$$E_3 = E_2\left[0.75 + 0.25\left(0.08 + \frac{3}{262.5} \times 0.78\right)\right]$$

$$E_3 = 0.772E_2$$

Thus for P_2 equaling average radiated power for a black picture we have:

$$\frac{P_2}{P_1} = \left(\frac{E_3}{E_2}\right)^2$$

$$P_2 = P_1 \times \left(\frac{E_3}{E_2}\right)^2$$

$$= P_1 \times \left(\frac{0.772E_2}{E_2}\right)^2$$

$$= (0.772)^2P_1$$

$$P_2 = 0.596P_1 = 0.596 \times 14.8 \text{ kw} = 8.82 \text{ kw}$$

Now let E_4 equal rms value of the average r-f voltage for a completely white picture. Here the carrier voltage drops to zero during all of the useful line time (if the transmitter is capable of full modulation, the standard requiring a drop to 15 percent voltage or less). From Figure 12–6 and the table of Figure 12–19 we see that there are 245½ useful lines per field, considering 6½ percent vertical blanking. A useful line lasts 84 percent of a horizontal line interval. Thus these 245½ useful lines per field drop the voltage from the 75 percent amplitude level to the 0 percent amplitude level.

$$E_4 = 0.772E_2 - 0.75 \times \frac{245\frac{1}{2}}{262\frac{1}{2}} \times 0.84E_2$$

$$= 0.772E_2 - 0.75 \times 0.935 \times 0.84E_2$$

$$= 0.772E_2 - 0.589E_2$$

$$E_4 = 0.183E_2$$

Then

$$\frac{P_3}{P_1} = \left(\frac{E_4}{E_2}\right)^2$$

$$P_3 = P_1\left(\frac{0.183E_2}{E_2}\right)^2$$

$$P_3 = 0.0335P_1 = 0.0335 \times 14.8 \text{ kw} = .496 \text{ kw}$$

Thus the average effective radiated power from a television station may vary from about 3 to 60 percent of its peak power, depending upon the nature of the picture.

Therefore, on a completely white picture we have a different average carrier voltage. Here the carrier voltage is zero during all of the useful line time. Let us assume that vertical blanking lasts for 7 percent of a vertical field interval. The horizontal blanking lasts for 16 percent of a horizontal line scanning interval. Thus the carrier is at zero amplitude.

Caution must be exercised in the operation of the television picture transmitter to maintain the radiated carrier envelope within closely specified tolerances. The pedestal (or front and back porch levels of synchronizing) must be maintained at 75 percent of peak radiated carrier. As the power drain varies in the transmitter depending upon the white content of the picture, it is sometimes necessary to alter the driving power in the input r-f circuit, since the regulation in the heavy-duty rectifier for the final stage cannot be perfect. Furthermore, the r-f amplifier circuits tend to saturate somewhat on the peaks of synchronizing because of the curvature of the amplifier tube characteristics. It is, therefore, customary to supply the video signal over the coaxial cable from the master control line amplifier at a level somewhat greater than 25 percent of the overall video signal. In some transmitters it is necessary that the amplitude of the synchronizing components be made as high as 40 percent of the overall video amplitude when pictures contain peaks of white. In this way, a portion of the 40 percent is available for compensation when the transmitter fails to modulate completely to zero carrier on the peaks of white. Another portion of this 40 percent may be consumed by saturation of the transmitter on peaks of synchronizing. However, the ultimate check on the 75 percent level for picture components and 25 percent additional level for synchronizing must be made on the r-f monitor or on a detecting diode which has been previously carefully calibrated from the r-f monitor and which carries the d-c component or residual carrier level corresponding to white in the picture.

The maintaining of proper distribution of amplitude levels between picture components and synchronizing components becomes somewhat more difficult when several relay transmitters are involved between the original camera equipment and

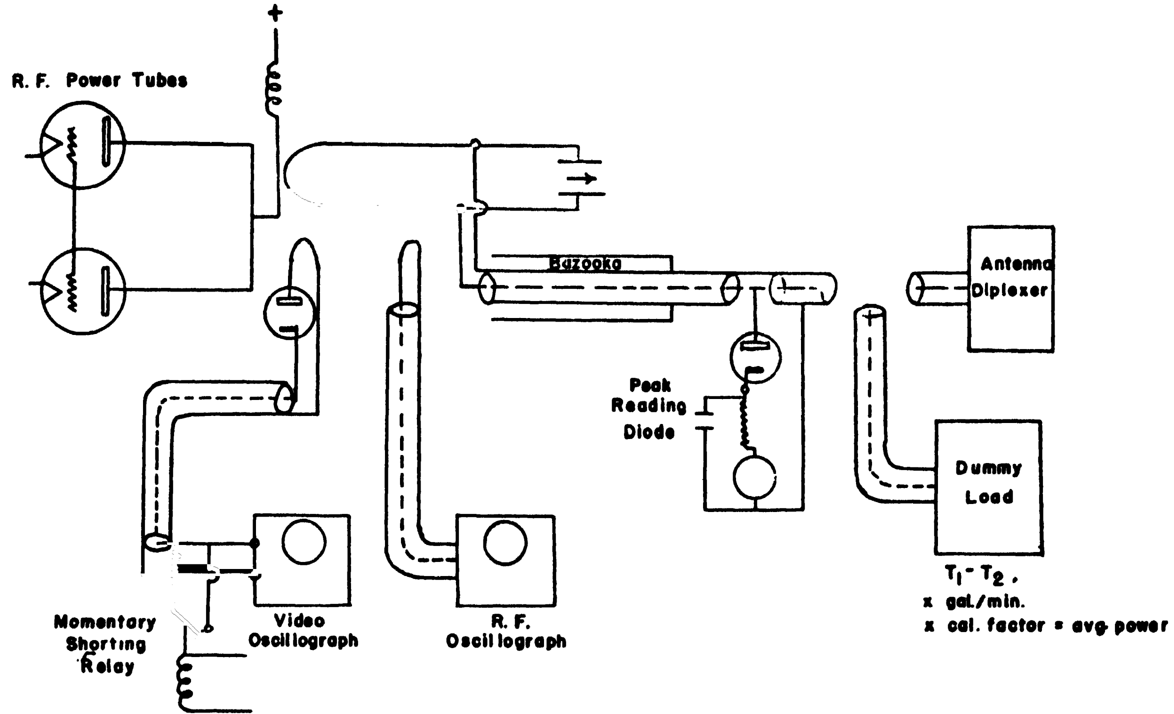

FIG. 12-59. Schematic of peak-reading diode.

the final broadcast transmitter. For example, it is customary to pick up television programs from one broadcasting station and amplify them and rebroadcast them from a second station. Presumably, the signals from the first broadcasting station may have the proper ratio of 75 percent picture to 25 percent synchronizing or 100 percent peak carrier voltage level. When such signals are received for rebroadcast purposes it is often necessary to employ a so-called sync-stretcher circuit in the amplifier chain. Such a circuit may be incorporated in the form of a cathode-follower amplifier, which somewhat compresses the picture components as they extend toward the white, thus accentuating in relative fashion the amplitude of the synchronizing signal. In some cases the synchronizing signals are actually skimmed off and carried through a separate amplifier channel and are reinserted on the picture signals at an appropriate amplitude. A typical sync stretching unit is Du Mont type 5057A as shown in the block diagram, Figure 12-61. This unit permits restoration of low-frequency response, removal of hum interference or low-frequency transients, and removal of sync tip modulation by use of special clamping circuits. The purpose of accurate maintenance of the standard of synchronizing may be more clearly understood in the discussion on Television Receivers.

12-22. Transmitting Antenna—In many television installations the television transmitting an-

FIG. 12-60

TYPICAL READINGS SHOWING POWER VARIATIONS WITH PICTURE CONTENT FOR A TELEVISION TRANSMITTER

Final R-f Stage

Type of Picture	R-f Wave Photo	Video Wave Photo	I_p = Plate Current	E_p = Plate Voltage	P_i = Input d-c Watts	Diode Volts	P_o = R-f Power on Sync. Peaks	Average R-f Power	Average R-f Efficiency
Measured:									
Black	Fig. 12–53	Fig. 12–52	1.75A	6000V	10,500	530	4000W	2380W	22%
Nearly White	Fig. 12–56	None	1.19	6200	7,378	590	4830	——	——
Test Pattern	Fig. 12–58	Fig. 12–57	1.25	6200	7,750	590	4830	——	——
Predicted:									
Pure White	None	None	——	——	——	---	100%	03.4%	——
Pure Black	None	None	——	——	——	— —	100%	59.6%	——

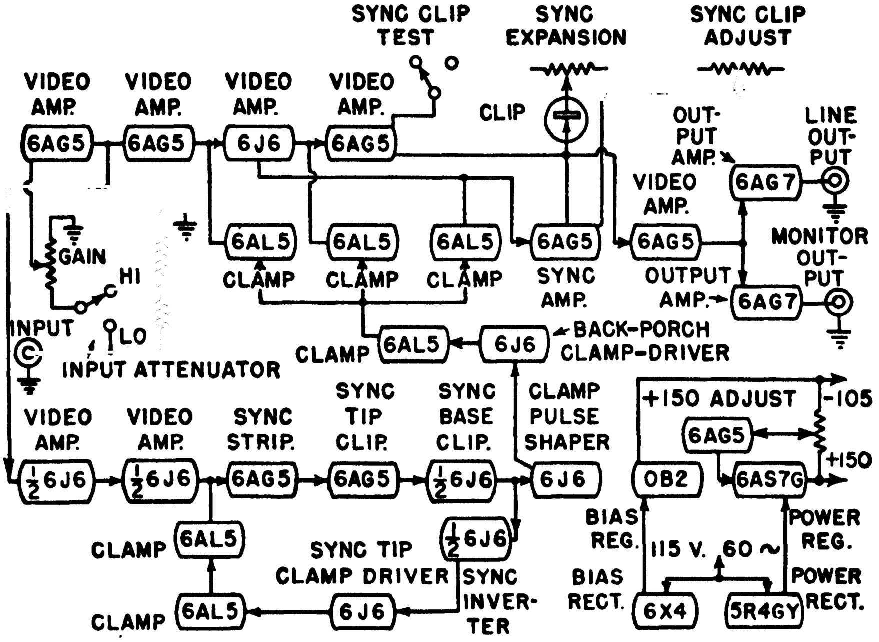

Fig. 12–61. Block diagram of DuMont type 5057A Sync Stretcher.

tenna consists of a super turnstile. This antenna is essentially a type of conventional turnstile antenna, but the shape of the radiators is such that the required bandwidth characteristics are obtained. The transmitting antenna of television station WABD, New York, shown in Figure 12–62, is such a super turnstile antenna. It is a three-bay arrangement with six pairs of "batwings" designed for omnidirectional coverage. In some specific locations the antenna may be directional if, for example, the transmitter is located on the side of a mountain and all of the service is in one given direction.

The turnstile antenna is fed by a pair of 51.9-ohm coaxial cables. These terminate in the diplexer which is a device to allow feeding both the visual signal and the aural signal to the turnstile without crosstalk. A high band diplexer for channels 7 to 13 is shown in Figure 12–63. This diplexer may be considered a bridge circuit as shown in the diagram, Figure 12–64.

The super turnstile antenna system has a very broad bandwidth as is necessary in order to keep the broad band characteristics of the entire transmitter from being vitiated. This type antenna is used for both sound and picture transmission. It has a power gain of approximately four on the low band television channels; the pole height is relatively small for this power gain.

Another type of video antenna is illustrated in Figure 12–65. This type of antenna has been installed on top of the Empire State Building in New York for station WNBT. The four bottom elements on the antenna are wide band turnstiles which carry both picture and sound. The power gain of this antenna is 3.3. The two triads above the turnstiles are WNBC–FM elements which approximate two loops in performance.

12–23. Routine Operating and Maintenance Procedures[4]—With the advent of television the radio engineer finds his duties multiplied manifold. In addition to his regular crew of broadcast men, he has added to his staff technical directors, video engineers, motion picture operators and men who operate the cameras, lights and mike booms.

The transmitter man now has two transmitters to operate as one unit; his vigilance and alertness will increase twofold.

The sound man, or gain rider, will find his duties more exacting, more exciting, and his sense of hearing as well as his sense of sight will have to be coordinated so that his cues will come in "on the button."

Scheduling the operating and maintenance crew is no small task in itself. Because of the long hours required for rehearsal of a television show, the crew that rehearses and learns the cues will have to be in most cases the same crew that puts the show on the air. The operating crew and the maintenance crew should be rotated in their duties so that the entire technical staff will become familiar with the complete television system. An understanding by each man on the technical staff of the complete television system will make for smoother all-round operation.

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[4] This section supplied by courtesy of Mr. Morris Barton, Television Engineer, Allen B. Du Mont Laboratories, Inc.

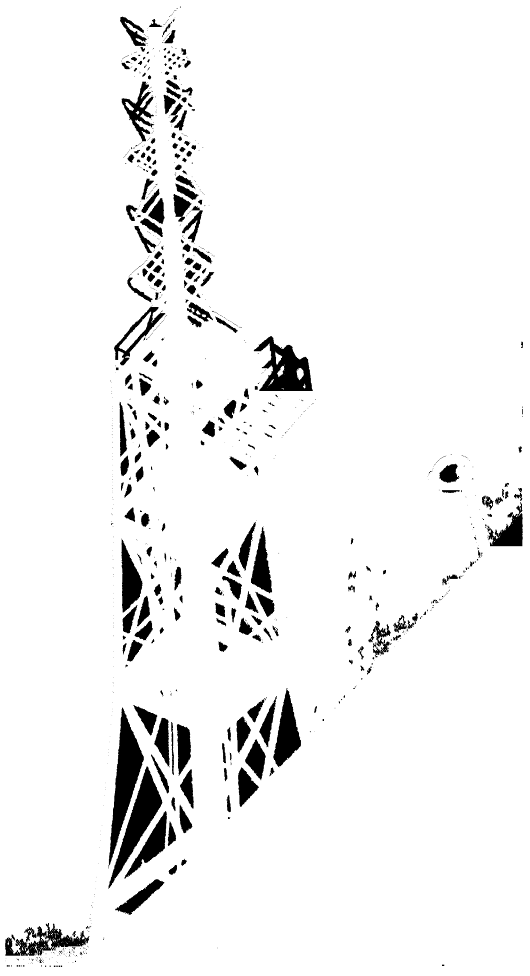


Fig. 12–62. Super turnstile transmitting antenna of television station WABD, New York.

The crew in the studio operate as a team, the signals, cues, directions and instructions coming from the program director and the technical director in the control room. All crew men wear earphones to receive these instructions.

During rehearsal of a show the technical director will have worked out with the director, the sound man and the mike man the proper placement of microphones, so that each scene will be planned to give the best audio pick-up with the least amount of studio noise. In order that each scene be properly illuminated for each camera, the technical director will work during rehearsal with the light man, the camera man, the video engineer and with the director on the proper placement of lights. The placement of microphones, lights, scenery, props and performers is marked on the cue sheet by the directors. The studio will have its stage director, who sees that the performers are properly guided on and off stage at the correct time and who sees that props are in their right places. He will also see that scenes coming up next are ready and scenes no longer needed are quietly shifted and new scenes put up in their places. The stage director, like all crew men, will also wear earphones to get his instructions from the director. If the director wants an actor to speed up a scene, the stage director will convey the director's wish to the actor by means of sign language.

While all this activity goes on during rehearsal, the cameras must be ON and ready to move at the director's command. Because of scene shifting and performers rehearsing lines and action sequences, there will be much time during rehearsal when the cameras are idle During this period of camera inactivity, lens caps should be placed over the lenses in order to protect the pick-up tubes from damage. A concentrated light beam such as a spotlight shining directly into the lens for a period of time would burn the mosaic. To avoid unnecessary use of equipment, the engineer should find out beforehand from the director how much of the rehearsal will be utilized as a camera rehearsal and how much for line rehearsal.

Since the light men, camera men, mike men and stage hands will all be moving around while the show is on the air, they will have rehearsal on how to move props to their proper places quietly without colliding with the mike man or getting in each others' way. The video engineer, because of so much activity in the studio, will want to test his cameras and equipment long before all this starts. Therefore, at least an hour before rehearsal or air time he should turn on the equipment to see that it is properly adjusted. The television equipment needed for a one-studio and one-projection room set up is as follows:

(a) Studio—four cameras, or else two cameras, each having a turret of several lenses.
(b) Projection room—two cameras.
(c) The control room houses the video and audio operating consoles, along with all the necessary equipment for each.

The audio system may be identified as a standard broadcast setup.

The video setup uses, say, a four-camera chain.

A camera chain is one camera plus all the equipment necessary to produce a picture ready to feed to the transmitter, namely:

1. Sync generator.
2. Blanking unit.
3. Camera.
4. Camera preamplifier and power supply.
5. Intermediate video amplifier and power supply.
6. Sweep unit amplifier and power supply.

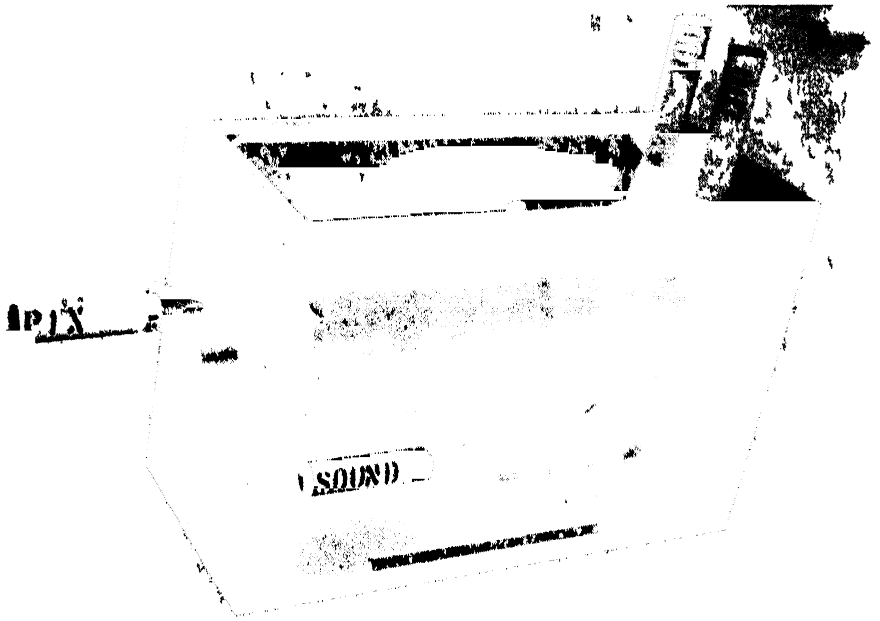


Fig. 12-63 High band diplexer—channels 7-13 (Courtesy RCA.)

7. Shading generator and power supply.
8. Line amplifier and power supply.
9. Twelve-inch magnetic station monitor and power supply.

Because the projection room and studio are close together, only one sync generator and blanking unit are used to drive the four cameras. The other three chains have duplicate equipment.

There is a preferred procedure for turning equipment on and off. The first unit to be turned on is the sync generator. Most sync generators have a built-in oscilloscope and after a warm-up period of a few minutes the oscilloscope by means of a rotary switch can be switched to the various frequency divider steps and each step checked from the master oscillator, 31.75 kc down to 60 cycles. Then the vertical and horizontal sawtooth waves are exam

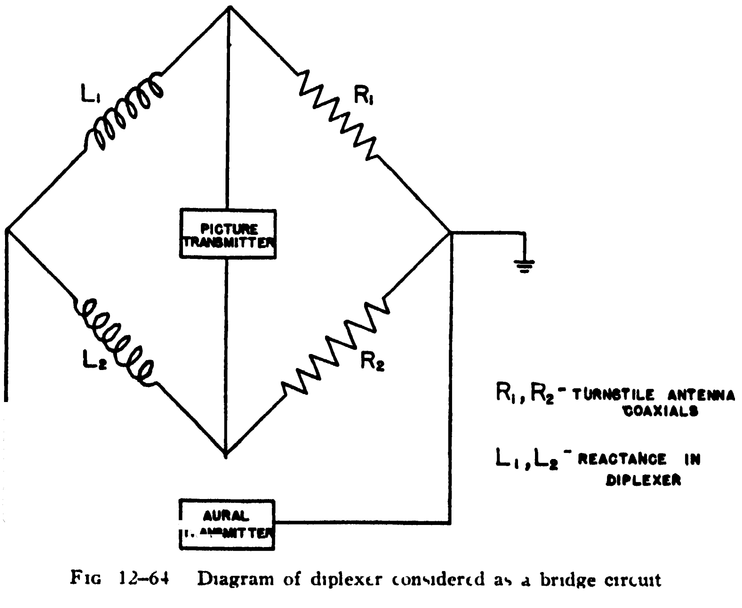

L1
R1
PICTURE TRANSMITTER
L2
R2
R1, R2 - TURNSTILE ANTENNA COAXIALS
L1, L2 - REACTANCE IN DIPLEXER
AURAL TRANSMITTER

Fig. 12-64 Diagram of diplexer considered as a bridge circuit

FIG. 12–65. Transmitting antenna of television station WNBT, New York. (Courtesy NBC.)

ined and the blanking signals checked. In this setup the switch that turns on the sync generator also lights the filaments of the rest of the equipment, except the filament for the iconoscope. The first rule to remember is: *the sync generator on first* and the *camera tube beam on last.* When turning the equipment off, turn the *camera tube beam off first,* and wait until the signal from the beam completely disappears before turning off the sweep circuit.

The rest of the equipment is turned on after the sync generator is working properly and all other filaments have heated, which is only a matter of a minute or two. Turn on the plate voltage for the camera control units, shading generators, line amplifiers, monitors and monitoring scopes. Of course, some installations will have time-delay relays to do this. Now check the camera to see if there are sweep signals to the yoke of the iconoscope or image orthicon. When this has been determined, it is safe to turn on the beam power supply for the camera tube. Then remove the lens cap and focus the camera on a test pattern, being careful to have the camera level and the test pattern straight, not at an angle. Be sure the test pattern is properly illuminated. Dolly the camera in and adjust optical focus until all edges of the test pattern completely fill the mosaic in the camera tube. After the optical focus is adjusted, check the electrical focus of the camera tube beam. Also check all regulated power supplies.

Now return to the control room to shade the picture, particularly because the iconoscope is not linear to light when using an iconoscope type of tube. The shading generator gives small voltages of various shapes to feed into the early video amplifier stages to correct for this nonlinearity to light. These voltages are in the shapes of horizontal sawtooth frequency, vertical sawtooth frequency, horizontal parabola or vertical parabola, and in some cases vertical and horizontal sine waves.

Next examine the picture on the monitor and monitoring scope to see if the picture is being properly scanned. Adjust the vertical sweep control until the top and bottom edges of mosaic are seen, then adjust the sweep back within the edge of mosaic. Adjust horizontal sweep to overscan until the left and right sides of the mosaic rim are seen. At this point the horizontal centering can be checked. Then reduce the horizontal scan within the mosaic edges. The vertical centering is also adjusted by slightly overscanning vertically, then centering the picture and reducing the sweep within the edges of the mosaic.

The next step is to adjust the linearity of the sweeps. To check the linearity, step back to the sync generator and turn on the vertical test bars. The bars are equally spaced and should show up equidistant on the viewing screen. For horizontal linearity, there are horizontal test bars to check the horizontal saw linearity in the same manner.

Next the blanking signals are checked to see that they are the proper width. These signals are identified as horizontal front and back porch and vertical front and back porch. Their width is measured on the oscilloscope and picture monitor.

Now check the keystone circuit. This is done by overscanning vertically and horizontally. Adjust the keystone control until the picture is the same width at the bottom as it is at the top and then bring the sweep back to normal.

Next, adjust the video gain and pedestal controls for the proper picture contrast. Move on to the line amplifier where the synchronizing signals are added to the picture. The standard R.M.A. signal must transmit a level of 75 percent picture with additional 25 percent sync as radiated by the transmitter. This level is adjusted in the line amplifier and read in percent off the scope, making allowance for the transmitter modulating characteristic.

At this point a composite picture is ready to be fed to the coaxial line to the transmitter.

Before rehearsal and before air time each camera should be set up with a test pattern and checked in this manner. The test pattern should now be fed to the transmitter and levels checked with the transmitter engineer. Also the test pattern is fed out on the monitoring lines and all monitors checked for proper brightness and contrast. The test pattern should be faded to black level to see that all monitors hold sync properly, and fade to black.

Operating the video transmitter is somewhat similar to operating and maintaining a broadcast transmitter. The sound transmitter is F-M and will comply with F-M standards and practices.

Tuning the video transmitter and antenna is the most difficult operation in the entire television system, due to the wide band of frequencies that the transmitter and antenna must pass. However, once it is tuned it will stay tuned for a long period of time. In cleaning and dusting the transmitter care should be taken so that no tuning adjustments are accidentally jolted. If this happens, more than likely the entire process of retuning will have to be repeated.

Starting with the crystal oscillator and doubler stages, these are tuned in the conventional manner and no difficulty should be encountered here. Next tune the r-f power amplifier in the conventional manner and proceed to the antenna.

The next step will be to disconnect the r-f drive from the first modulated amplifier and connect in its place a power variable-frequency sweep oscillator, which is sometimes called a wobbulator. These variable frequencies are of constant amplitude and frequency-modulate the r.f. back and forth at a bandwidth of 7 to 10 mc. A diode rectifier with a short antenna is placed in the field of the first modulated amplifier and the output of the diode fed to an oscilloscope. This r-f modulated amplifier is tuned by adjusting the coupling, the grid capacitance, the plate capacitance and the value of the grid damping resistors until a flat response is noted on the oscilloscope for the desired bandwith characteristics as required by the F.C.C. If the transmitter is low-level modulated, this procedure is followed through to the final amplifier.

The television antenna is usually pretuned before it is raised to the top of the mast, and the only adjustment left will be the amount of coupling desired.

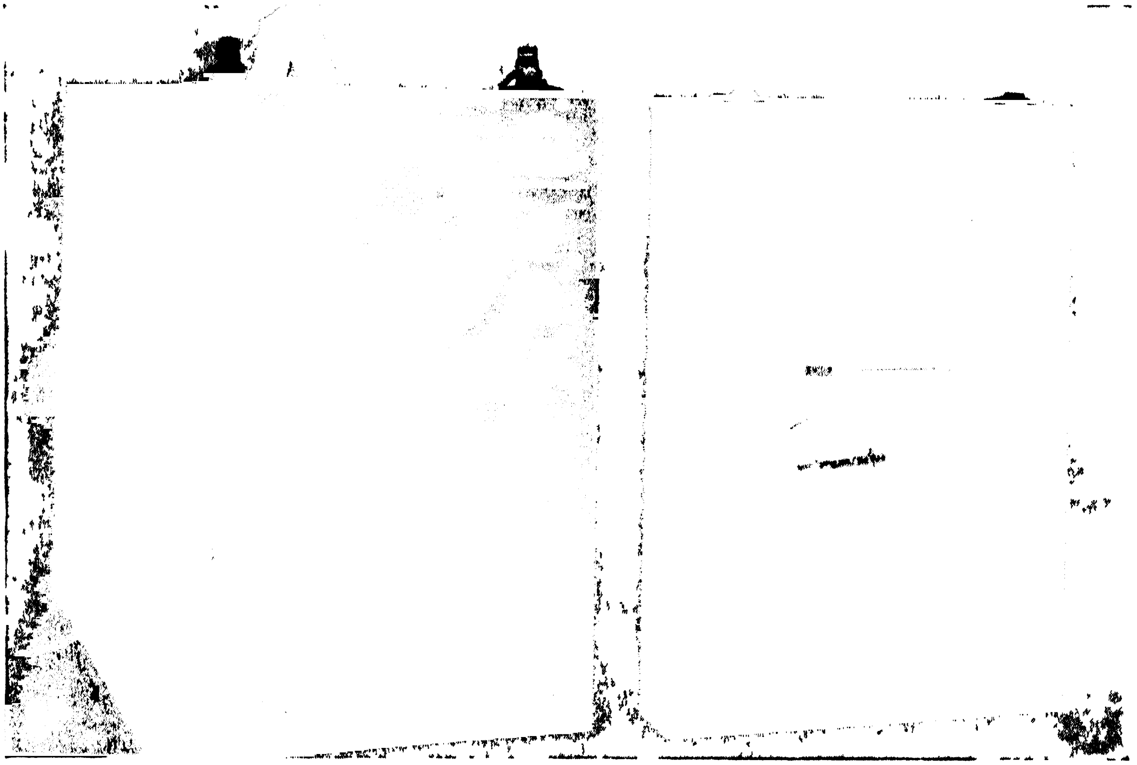


FIG. 12–66. Type 241 cathode-ray oscillograph.

The transmitter engineer will, of course, have a picture monitor as well as a loud-speaker monitor to see and hear the quality of transmission. Logs of both transmitters will have to be kept and the engineer will be concerned with keeping the transmitters operating in accordance with all requirements of the F.C.C.

Maintenance of the television transmitter will follow general broadcast procedure. The water system is inspected and cleaned, motors and pumps cleaned and oiled on a regular maintenance schedule. A liberal supply of spare tubes and components must be available.

12-24. Television Test Equipment—Test equipment for the television station must be capable of measuring wide frequency bands, low and high voltages, and peculiar waveshapes, the signals to be tested many times appearing at high impedance. Extreme requirements are, therefore, placed upon the test equipment. High-impedance vacuum-tube voltmeter units are desirable, such as the RCA Voltohmyst, for routine continuity tests and measurements of various socket voltages throughout the equipment.

A good general purpose cathode-ray oscillograph is an absolute *must* in adjustment and maintenance of television equipment. Figure 12-66 shows a Du Mont type 241 oscillograph, which is designed for television testing. This oscillograph has vertical deflection amplifiers of sufficient sensitivity to test the signals throughout the television equipment and has frequency response to 2 mc. The r-f signals from the transmitter may be applied directly to the deflection plate terminals on the front panel, so that this type of oscillograph may be used for monitoring the carrier envelope. A circuit diagram for the type 241 oscillograph is shown in Figure 12-66a. The following chart, Figure 12-67, gives its specifications.

In testing r-f circuits, it is desirable to have a high-level signal generator which may be frequency modulated or wobbulated to cover the entire band pass of the circuits under test. Figure 12-68 illustrates a typical circuit for such a wobbulator. It incorporates a variable-frequency oscillator whose frequency is shifted by a mechanically rotated capacitance. Another calibrated oscillator may be tuned slowly through the desired band pass so that an observation of the zero beat between the two oscillators will determine the exact frequency which produces a given response in the circuit under test. Such a wobbulator feeds its signals through an output amplifier tube to the circuit under test. An oscillograph is then connected directly to the output of this portion of the circuit under test with r-f connections, or else a detecting diode is inserted between the circuit, under test and the input to the oscillograph. In one case a radio-frequency envelope picture is obtained and in the other case a

Du Mont Type 241 Cathode-Ray Oscillograph

SPECIFICATIONS

Cathode-ray Tube:

Type	5JP1/2529A5
Accelerating Potential (overall)	1500 volts

Input Impedance:

	Terminals	*Probe*	*Direct (Balanced)*	*Direct (Unbalanced)*
Y-axis	2 meg 40 μμf	1 meg 10 μμf	5 meg 20 μμf	5 meg 25 μμf
X-axis	2 meg 40 μμf		5 meg 20 μμf	5 meg 25 μμf
Z-axis	1 meg 20 μμf			

Maximum Input Potential:

Y-axis through amplifier	400 rms signal volts (600 vdc max.)
Y-axis direct to plates	400 rms signal volts (600 vdc max.)
X-axis through amplifier	50 rms signal volts (600 vdc max.)
X-axis direct to plates	400 rms signal volts (600 vdc max.)
Z-axis	5 rms signal volts (600 vdc max.)
External synch voltage	10 peak to peak signal volts (600 vdc max.)

Amplifier Frequency Response:

Y-axis	Uniform within 3 db from 20 cycles to 2 megacycles at any attenuator setting. 6 db down at 4 megacycles.
X-axis	Uniform within 3 db from 5 cycles to 100 kilocycles per second at any attenuator setting. 6 db down at 300 kilocycles per second.
Z-axis	Uniform within 3 db, 30 cycles to 2 megacycles per second.

Deflection Factor:

With Amplifier:	
Y-axis (Terminals)	0.07 rms volts/inch
Y-axis with probe	0.70 rms volts/inch
X-axis	0.70 rms volts/inch
To Deflection Plates:	
Y-axis	22 rms v/inch
X-axis	21 rms v/inch

Linear Time-Base:

Frequency Range	15 to 30,000 cps
Direction of Sweep	Left to right
Synchronizing Signal Sources	Internal (Y-Signal), 60 cycles, External
Synchronizing Polarity	Either polarity of synch. signal

Power Supply Source:

Potential	115 rms volts
Power Consumption	160 watts
Frequency	50/60 cycles
Fuse Protection	3 amps

Physical Specifications:

Height	17½ inches over all
Width	20¾ inches over all
Depth	21 inches over all
Weight	65 pounds
Housing	Portable steel cabinet with carrying handle
Front Panel Finish	Satin finish plate

Fig. 12-67.

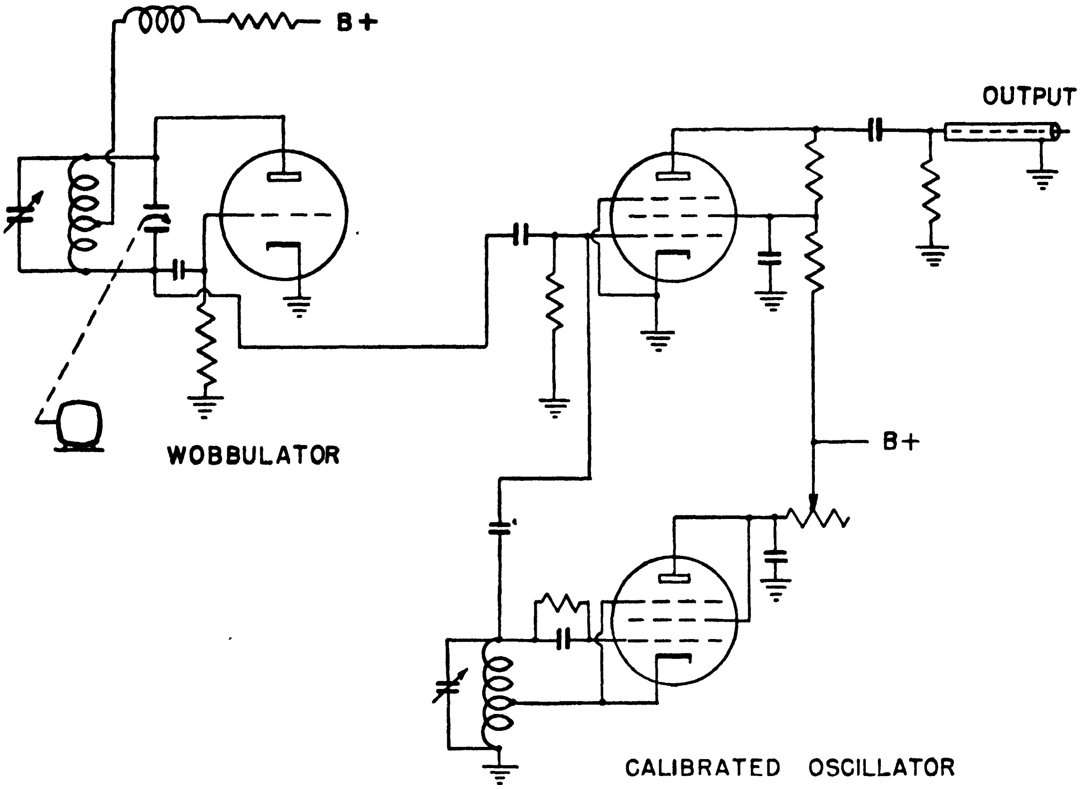


Fig. 12–68. Circuit of wobbulator for television testing.

curve showing amplitude response versus frequency is obtained on the oscilloscope.

It is customary to synchronize the sweep circuit of the oscillograph with the rotational speed of the wobbulator motor so that the curve remains stationary for measurements. In practice, the wobbulator motor is a synchronous motor operating at 1800 rpm. Precautions must be taken to minimize power supply hum levels in measurement circuits, so that these fixed-amplitude hum signals are not mistaken for frequency response characteristics. To minimize such a misinterpretation, it is sometimes desirable to drive the wobbulator condenser at a speed slightly away from 1800 rpm, so that hum signals will crawl on the oscillograph pattern while the true frequency response curve will remain synchronous with the wobbulator scan frequency.

In testing a video amplifier a wobbulator similar to that shown in Figure 12–68 is employed, except that the frequency-modulated oscillator swings from the same frequency as the calibrated oscillator up to a frequency about 10 mc away from the calibrated oscillator. The calibrated oscillator may, for example, operate at 100 mc and the wobbulated oscillator between 100 and 110 mc. The output tube is designed to pass only the beat frequency which will vary from zero cycles per second to 10 mc per second. Such a circuit is called a video-frequency wobbulator and is extremely useful in testing the frequency response characteristics of video amplifiers. The combination of this video wobbulator and a good oscillograph makes it possible to adjust the video amplifier stages throughout the television station for excellent frequency and phase response. Variations of capacitance when replacing tubes may upset the correct adjustment of a variable-inductance peaking coil, and the use of such a test wobbulator makes it a simple process to readjust the alignment on video amplifiers when tubes or components need replacement.

For much of the test work in television design and equipment maintenance, an oscillograph with a triggered horizontal sweep as well as a repetitive synchronous sweep is desirable. A typical instrument of this type is the Du Mont type 280 television test oscillograph, shown in Figure 12–69.

A triggered horizontal sweep allows the operator to examine the waveform for a single horizontal line of the composite picture, with sweep delays to select the line desired. Auxiliary circuits may be provided to allow the fields to be selected, and so successive picture lines may be compared without delaying the sweep one complete field duration. The sweep may be triggered from selected synchronizing pulses of the composite video signal.

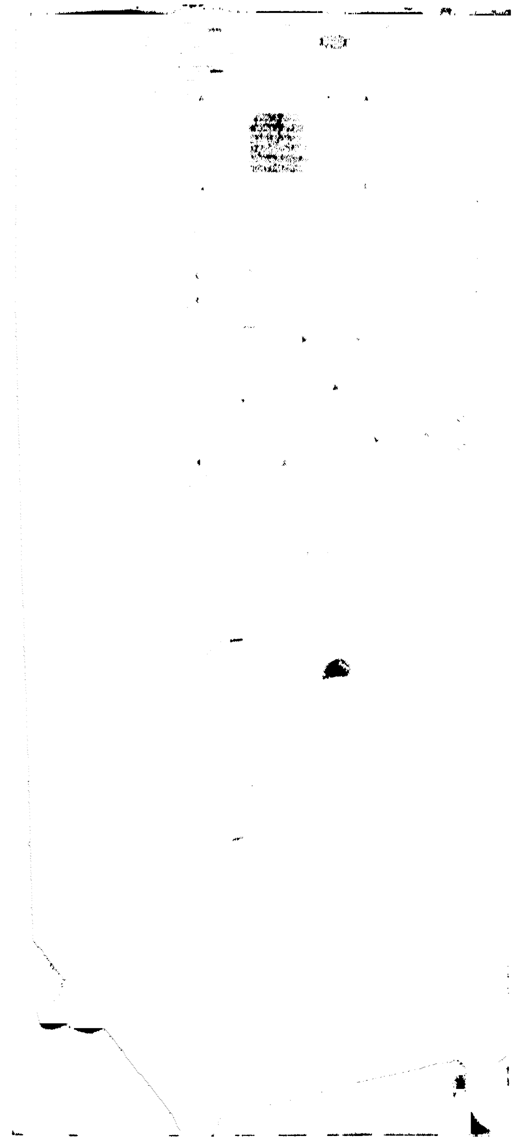


Fig. 12-69. DuMont type 280 cathode-ray oscillograph.

The cathode-ray tube beam writing rate in oscillographs for such application is quite rapid. For ease in viewing the video signals it is desirable for the cathode-ray tube accelerating voltage to be increased. This, of course, decreases the deflection sensitivity so that the final value of accelerating voltage reached is a compromise between beam trace brightness and deflection sensitivity.

Synchronization may be external or internal either on composite video or transient signals. The horizontal sweep duration may be set from 15,000 microseconds to 1 microsecond, and the start of the sweep may be delayed up to 1000 microseconds. The sweep triggering pulses may be selected from a composite video signal to display either successive lines or fields. The operating sensitivity is a maximum of 0.28 volts peak to peak per inch of deflection. The cathode-ray tube accelerating voltage may be set at any point from 2 to 10 kv.

Figure 12-70 is a photograph taken with this oscillograph showing two horizontal blanking pulses separated by linearity test pulses. The transient response of the deflection amplifier gives a resultant bandwidth down 3 db at 10 mc.

Good light meters are very useful in determining a proper balance of studio set lighting.

12-25. Television Receivers—The television receiver must accept signals which have been transmitted by radio and convert these signals to the pictures and sound of the television program. An average receiver draws about 300 watts of power from the 60-cycle power line and contains 20 to 30 tubes. The arrangement of a table model chassis is shown in Figure 12-71. The table model shown is a Du Mont type 103 set employing a twelve inch electromagnetic-deflection cathode-ray tube with an electron beam accelerating voltage of 10,000 volts. The circuit diagrams for this 12-inch receiver are shown in Figures 12-72, 12-73, and 12-74. They may be analyzed into the following functional sections:

(1) R-f circuits. The incoming signals picked up by the antenna are conducted to the input of the television receiver by means of a 73 ohm, low-loss transmission line (coaxial cable). The transmission line is terminated by the cathode input circuit of the grounded-grid r-f amplifier V101. This input circuit is capacitively coupled to the transmission line by means of condenser C101. The untuned input circuit has been designed so that it

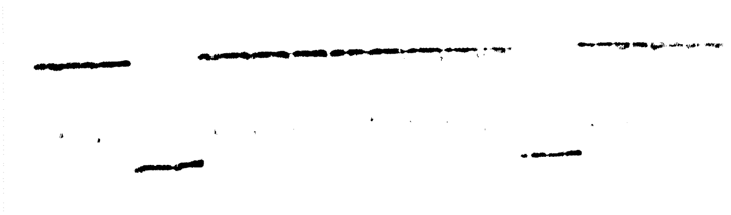


Fig. 12-70. Oscillogram showing 2 horizontal blanking pulses separated by linearity test pulses. (34 micro-seconds/in. on 5-in. tube.)

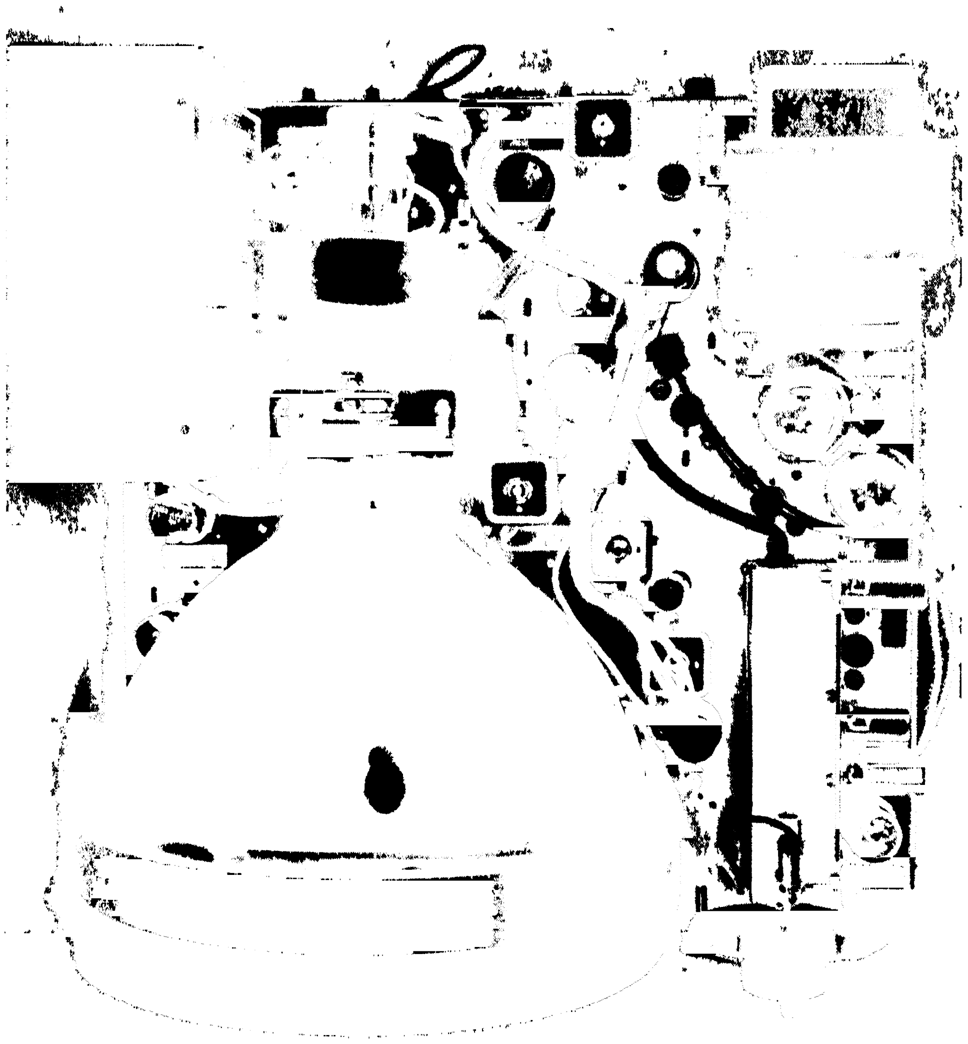
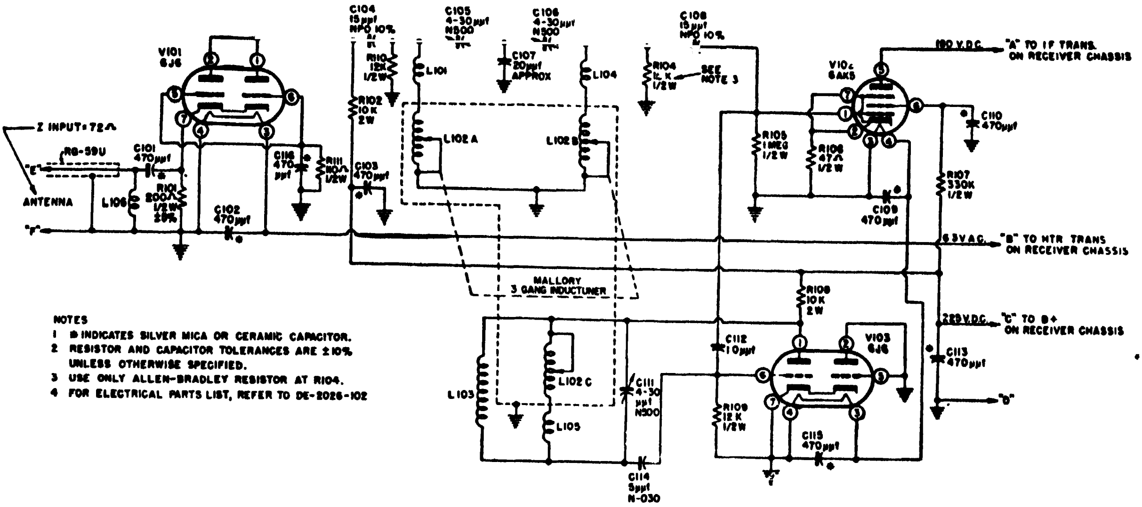


Fig. 12-71. Chassis of DuMont Model 103 receiver showing location of components (Courtesy DuMont)

presents the proper impedance match to the transmission line over the entire tuning range from 44 to 216 mc. The inductance L106 in parallel with the antenna input provides a high-pass, radio-frequency filter to suppress broadcast-band or other low-frequency, cross-modulation interference which may arise when the television receiver is located in an extremely intense field of a local A-M broadcast station or other radiator.

The plates of the r-f amplifier (V101) are coupled to the grid of the mixer tube (V102) by means of a 6-mc wide broad-band coupling network. The variable series coil combinations consisting of L101-L102A and L104-L102B tune to the desired signal frequency in conjunction with the associated tube capacitances and the coupling network consisting of C105, C106 and C107. Resistors R110 and R104 reduce the *Q* of the respective coils considerably in order for the coupling network to maintain the very wide pass band.

The VHF oscillator utilizes one section of the twin triode (V103) in a modified Colpitts oscillator circuit. The feedback voltage from the plate to the grid of the oscillator tube is accomplished by means of the interelectrode capacitance of the vacuum tube. The oscillator frequency is adjusted by movement of the tap on the coil L102C which short circuits a portion of the coil. The oscillator circuit



NOTES
1 * INDICATES SILVER MICA OR CERAMIC CAPACITOR.
2 RESISTOR AND CAPACITOR TOLERANCES ARE ±10% UNLESS OTHERWISE SPECIFIED.
3 USE ONLY ALLEN-BRADLEY RESISTOR AT R104.
4 FOR ELECTRICAL PARTS LIST, REFER TO DE-2026-102

FIG. 12–72. Schematic of r-f tuner of DuMont model 103 television receiver.

is factory aligned to track with the signal circuits located in the plate of the r-f amplifier V101 by adjusting the inductance of L103 and capacitance of C111.

The oscillator output is coupled to the grid of the mixer tube V102 by means of condenser C112. Both the incoming signal and the oscillator voltages are fed into the grid of the mixer tube V102. The plate of V102 feeds into the first video i-f transformer. Station tuning over the television and F–M bands is accomplished by rotation of the three inductances comprising the inductuner.

(2) The sound i-f channel consists of an i-f stage V207 after some amplification has already been achieved in the 1st video amplifier, the limiter V208 and a conventional F–M discriminator V209. R244 and C234 make up the de-emphasis network. The sound i.f. is 21.9 mc and is designed for ± 75-kc modulation of standard F–M stations as well as ± 25 kc of television sound modulation.

(3) *Video i-f Amplifier.* The video i-f amplifier chain consists of three stages using the sharp-cutoff high-gain pentode (V201, V202 and V203). See Figure 12–73. Each video i-f coupling network consists of two adjustable coils which are resonant with their respective tube capacitances and coupling networks. The first video i-f coupling network utilizes shunt inductive coupling, the second and fourth video i-f coupling networks use the series type of inductive coupling, and the third network is a specially terminated *m*-derived band-pass filter network. The two parallel resonant traps in the series arm of the pi network in the third coupling network provide a high degree of attenuation to the sound carrier of the station being received and to the sound carrier in the adjacent channel.

The grids of the first and second video i-f stages, V201 and V202, are returned to a variable negative bias provided by the contrast control, which thus varies the gain of the i-f amplifier. The third video i-f amplifier stage is operated at maximum gain. The input to the F–M sound i-f amplifier system is taken from the plate of the first video i-f amplifier V201.

The output of the fourth video i-f coupling network is fed into one diode section of the video detector V204A and the diode load which consists of resistor R219 and peaking coils L213 and L214.

(4) *Video Amplifier.* The grid of the video amplifier tube V205 is directly connected to the diode load. A fixed bias of — 3 volts (when no signal is present) is maintained on the grid of the video amplifier V205 by returning the low potential end of the diode load resistor R219 to the — 3 volt point of the bleeder resistor network consisting of R216, R220 and R233.

The plate of the video amplifier is coupled to the type 12JP4 teletron, V206, by means of the resonant trap consisting of L216 and C217, and condenser C218. This resonant trap is tuned to 4.5 mc and provides the video amplifier section with an extremely sharp cutoff characteristic, thereby contributing to the elimination of interference from the sound carrier of the incoming television station.

(5) *D-c Restorer and Sync Separator.* The plate of the video amplifier is also coupled to the second section of the vacuum tube V204B and the diode load consisting of R256, R225 and C282. This circuit rectifies the composite video signal and reinserts its d-c component onto the grid of the Teletron V206. The diode section of V204B also serves as a sync separator since negative composite sync pulses appear across R225.

(6) *Teletron Controls.* The BRIGHTNESS CONTROL, R227, varies the positive d-c bias on the cathode of the Teletron so as to vary the picture background brightness. The Teletron BIAS CON-

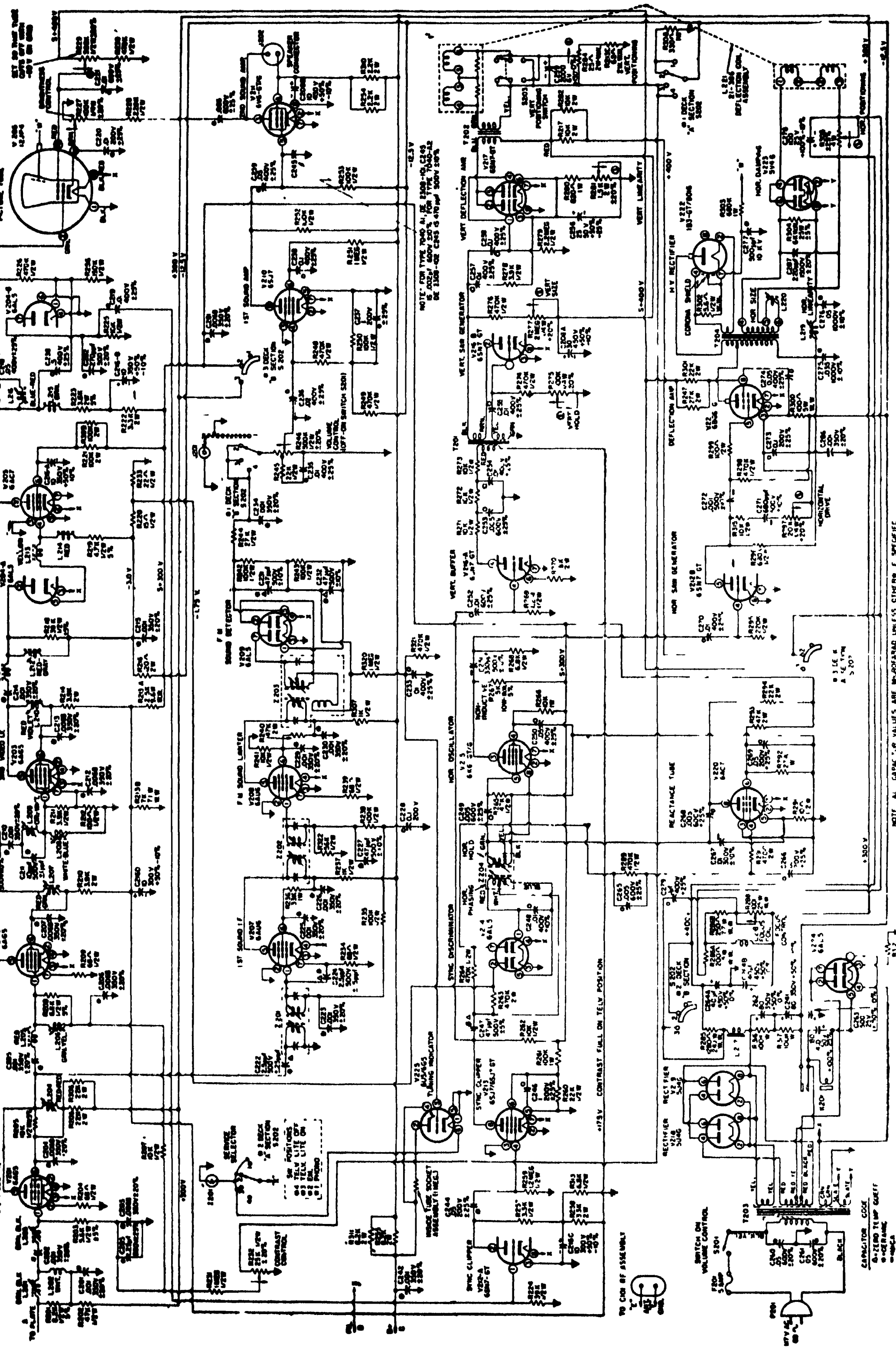
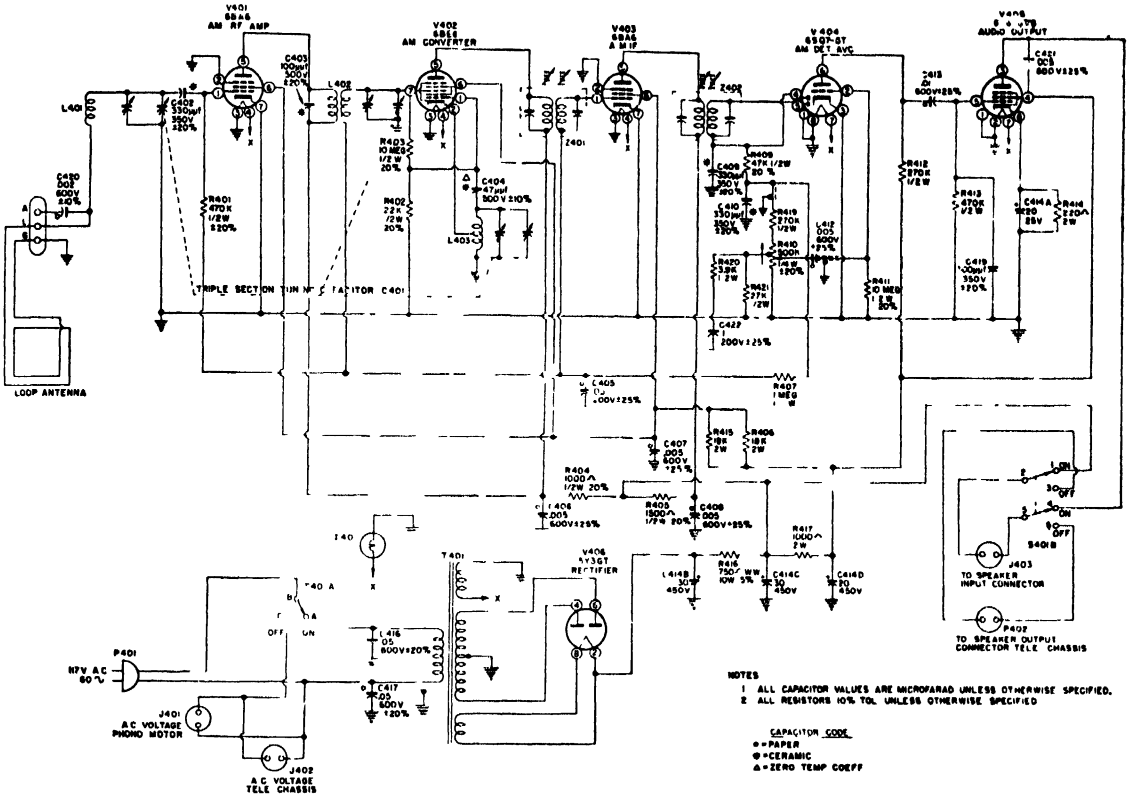


FIG. 12-73. Schematic of main circuits of DuMont model 103 television receiver.



NOTES
1 ALL CAPACITOR VALUES ARE MICROFARAD UNLESS OTHERWISE SPECIFIED.
2 ALL RESISTORS 10% TOL UNLESS OTHERWISE SPECIFIED

CAPACITOR CODE
● = PAPER
● = CERAMIC
▲ = ZERO TEMP COEFF

FIG. 12-74. Schematic of A-M tuner for DuMont model 103 console television receiver.

TROL., R229 (one of the non-operational controls located on the chassis), varies the positive voltage on the second grid of the Teletron. The purpose of this control is to adjust individual Teletrons so that they all have a standard grid control characteristic when used in the Teleset.

(7) *Sync Clippers.* The composite sync pulses developed across R225 and C282 are coupled into the two sync clipper stages consisting of V212A and V213. The clipper stages amplify and clip both top and bottom of the sync pulses. The sync pulses developed on the plate of the second stage remain substantially constant in amplitude over a wide range of input signal level.

(8) *Vertical Deflection.* The output of the second sync clipper is fed into the vertical buffer V216A, the plate load circuit of which consists of an integrating network and one winding of the vertical blocking oscillator transformer T201. The vertical buffer amplifies and integrates the serrated vertical sync pulses and provides sharp vertical sync pulses which trigger the vertical blocking tube oscillator V216B. The VERTICAL HOLD CONTROL, R275, adjusts the free running frequency of the blocking oscillator.

A sawtooth voltage is generated by charging condenser C257 through the series resistances consisting of resistor R276 and the VERTICAL SIZE CONTROL R277. The time constant of this network controls the amplitude of the sawtooth voltage.

The vertical deflection amplifier V217 converts the sawtooth voltage to the linear sawtooth current required for deflection. The vertical linearity control R281 varies the cathode bias of the vertical deflection amplifier V217 which in turn controls the degree of curvature over the operating portion of the E_g-I_p curve of this tube. This curvature compensates for an opposite curvature produced by the output transformer and vertical deflection coils, resulting in a linear change in current in the deflection coils.

The plate current of the vertical deflection amplifier V217 is fed into the vertical deflection coils by means of the vertical output transformer T202. The VERTICAL POSITIONING CONTROL R284, in conjunction with the VERTICAL POSITIONING SWITCH S203, adjusts the amount and polarity of d-c current in the vertical deflection coil to center the picture properly on the screen of the Teletron tube V206.

(9) *Horizontal Sync and Deflection.* The horizontal sweep is triggered by the sine-wave electron-coupled oscillator V215. The free running frequency of approximately 15,750 kc is determined

primarily by the oscillator winding in transformer Z204 and by condenser C267. The HORIZONTAL HOLD CONTROL is a powdered iron movable slug in this winding which varies its inductance. The exact frequency, however, is controlled by the repetition frequency of the incoming horizontal sync pulses. Synchronization is accomplished as follows:

The output of the horizontal oscillator is compared with the incoming horizontal sync pulses in the discriminator circuit of V214. The resulting d-c "error" voltage which is developed across the discriminator load resistors R263 and R264 will vary in amplitude and polarity depending upon the relative difference in phase between the sine-wave oscillator and the incoming sync pulses. The d-c error voltage which is impressed upon the grid of the reactance tube V220 causes the plate current and transconductance of the reactance tube V220 to vary accordingly. The capacitive reactance which the reactance tube V220 presents to the tuned circuit is, therefore, varied, causing the oscillator to shift phase in proportion to the amount of the error voltage, and in the direction to bring the oscillator into phase with the incoming sync pulses. Thus, the oscillator is locked to the sync pulses.

The actual phase relationship between sync pulses and oscillator can be varied by means of the PHASING CONTROL, a powdered iron slug in the discriminator winding of Z204, so as to make the picture start at just the right place horizontally on the raster.

The output from the plate of the horizontal oscillator is fed into the differentiating network consisting of condenser C251 and resistor R268. The sharp tips of the differentiated positive pulses cause the horizontal sawtooth generator V212B to discharge the sweep generating condenser C271, thereby initiating the return trace of the horizontal sweep. The charging time-constant network consisting of R296, R315, C271 and the HORIZONTAL DRIVE CONTROL R297 is returned to the most negative point in the power supply through the cathode bias resistor R300 controlling the amount of sweep voltage impressed upon the grid of the horizontal deflection amplifier V221; the horizontal drive control adjusts the linearity of the beginning and end of each horizontal trace.

(10) *Horizontal Output Amplifier and High-voltage Power Supply.* The high voltage required to accelerate the electron stream in the Teletron V206 is generated by a "flyback" type of power supply. During the return trace of the sweep the energy which is stored in the horizontal deflection coil circuit is fed back into the primary winding of the horizontal output transformer T204 in the form of a very sharp negative pulse. This pulse is increased in amplitude by autotransformer action in the primary winding and is rectified by the high voltage rectifier V222. The rectified energy which is stored in the high-voltage condenser C277 is used to accelerate the electron stream in the teletron.

The horizontal damping tube V223 and the damping resistor, R304, critically dampen the ringing in the horizontal deflection yoke which occurs during the line retrace period. Part of the energy so absorbed is utilized to "boost" the plate supply voltage of V221 by feeding the B supply in series with the voltage developed across the damper tube V223 on to the plate of the horizontal deflection amplifier V221. The horizontal linearity network consisting of L219, C275 and C276 is used to shift the phase of the booster voltage. By shifting the phase of this booster voltage with respect to the plate current requirements of V221, slight variations of plate characteristics are obtained. The HORIZONTAL POSITIONING CONTROL, R305, controls the d-c current through the horizontal deflection coils.

(11) *Power Supply.* The low-voltage power supply of the television receiver is obtained from a pair of 5U4G rectifiers connected for full-wave, high-current rectification, with conventional filtering.

The low-voltage power is applied to the receiver by the closing of the time delay relay K201. This relay is energized by the diode current of V224. The relay circuit has been designed so that the relay is energized approximately 10 seconds after the power is applied to the television receiver. In this way all condensers and other components are protected from the high surge voltage which otherwise would occur before the tubes heated up and started to draw plate current.

(12) *Focus Coil and Control.* The focus coil, L218, is in series with the section of the power supply which delivers 300 volts to most of the circuits. The current drain of these circuits provides more than enough current for proper focus. The focus current is adjusted to bring the Teletron to precise focus by means of the FOCUS CONTROL R288, which is a variable resistor shunted, together with R286B, across the focus coil.

There are many types of television receivers similar in principle to the one just described. They employ tubes ranging in size from 7-inch diameter to 20-inch diameter, with electrostatic focusing and deflection or magnetic focusing or magnetic deflection, some designed for direct viewing, others for mirror viewing, and others for home projection and theater television projection. Many models incorporate broadcast reception as well as television. Many of these receiver designs accommodate the thirteen commercial television channels between 44 mc and 216 mc, and the F–M broadcast band from 88 mc to 108 mc. With so many stations, it is best to use some device such as the continuously adjustable inductive tuner with a motor-driven push-button tuning mechanism. Suitable controls can allow the optional use of the picture portion of the receiver and use of the sound portion for either aural broadcast or for television.

12–26. Propagation Characteristics—Propagation matters are treated quite fully elsewhere in this book, but a few points specifically related to television may be emphasized here to advantage. The general conception of fading and other propagation distortions associated with communication or sound broadcast circuits are also critical in television broadcasting. However, many of the long-distance characteristics of communications channels do not concern television because, as we have already explained, television involves a very wide band of modulating frequencies and consequently utilizes relatively high carrier frequencies, the commercial channels now lying between 54 mc and 216 mc. Thus reliable long-distance reception over skywave paths is not generally provided.

However, a television system is sensitive over a wide band of frequencies for a given station, responding to top video frequencies of 4.5 mc. A picture element conveyed by a 4-mc video signal thus may be produced in a time interval of one-half cycle of this 4-mc wave. Thus the time interval required to produce a picture element in the finest resolution portion of a television picture is of the order of a tenth of 0.1 microsecond. On the other hand, sound broadcasting, employing frequencies up to 15 kc per second, involves at least the resolvable time of 67 microseconds. Radio energy travels at the rate of approximately 186,000 miles per second or one mile in 5.38 microseconds. Thus signals arriving at an antenna over two paths which differ in length by the order of a mile would be sufficiently displaced in time to produce a very noticeable double signal on television because the 5 microseconds is long in comparison with the one-tenth microsecond which can be resolved. On the other hand, sound broadcasting signals arriving over two paths having a path difference of the order of a mile would be so nearly in phase that little or no distortion would be observable, since 5 microseconds is very small in comparison with 67 microseconds, which is the least discernible phase-error interval.

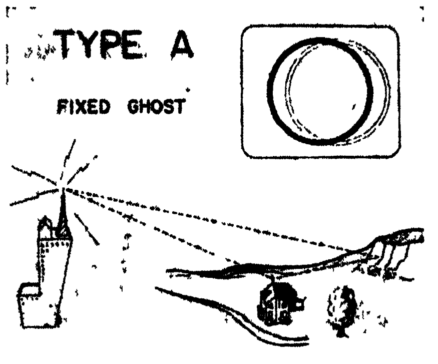


Fig. 12–75. Conditions which may produce a type "A" fixed ghost.

Thus we see that in television we have a different propagation consideration from that involved in sound broadcasting. These propagation characteristics, which produce multiple images, are called multipath phenomena. The multiple images viewed on the television tube are referred to as ghost patterns.

Figure 12–75 illustrates a typical condition which may produce one of the most common types of fixed ghost patterns. Figure 12–76 is a photograph showing such a fixed ghost caused by a secondary path reflection from a hill approximately one-half mile beyond the receiver in a direction away from the transmitter. By measurement of the extent of displacement of the ghost pattern from the main pattern, and by study of the data in the table of Figure 12–19, it can be seen that the reflection produces a time delay of about 5 microseconds, which is characteristic of about one mile extra path length for this secondary path and which includes one-half mile to the hill and one-half mile return path.

Fig. 12–76. Reflection ½ mile from receiver.

These fixed ghosts are generally produced by fixed objects, but airplanes flying overhead may produce momentary displaced ghosts which are termed type D, or pulsating ghosts. This condition is most serious where the receiver is located in an area shielded from strong direct transmission signals. In such a condition the airplane may reflect more energy over the secondary path than the receiver normally gets over the primary path and the pulsating ghost pattern may actually be strong enough to take over the synchronizing.

In Figure 12–76 the white portion of the "C" in N.B.C. is reproduced in the ghost image as a black image, illustrating what is known as a type E or negative ghost. This negative ghost is produced by a suitable phase of the secondary signal with respect to the primary signal occurring on a suitable amplitude range of the received primary signal.

Careful study of these ghost patterns can best be made by observing television signals on a receiver and antenna which are in motion in an automobile or a boat through territory involving high buildings or hills.

In some locations a strong main signal may predominate, but a number of lesser energy signals may arrive over a variety of paths differing only slightly in path length from the major signal. A pattern received under these conditions may exhibit a type B or "smear" ghost, which tends to lower the resolution in a horizontal direction. Conditions which may produce this type B or smear ghost are illustrated in Figure 12-77.

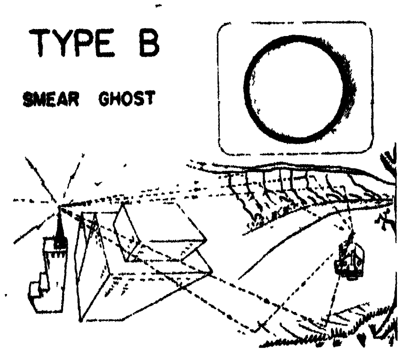


Fig. 12-77. Conditions which may produce a type "B" smear ghost.

At the carrier frequencies employed for television, the signals tend to follow optical paths, due to their relatively short wave lengths, and thus shadows may be produced by objects such as buildings and hills. It is in general true that best television reception may be obtained where the receiving antenna is in line of sight from the transmitting antenna, or very nearly so. A slight curving of the radiation may take place around the curve of the earth. However, it is most advantageous for the transmitting antenna to be located on a high elevation which tends to minimize multiple-path conditions and which tends to give the greatest line-of-sight coverage when the earth's curvature is taken into consideration. For example, an antenna 1000 feet above the average ground level will reach to an optical horizon of a distance of about 40 miles and to a quasi-optical horizon at a distance of approximately 50 miles when the bending of the radio energy about the earth's curvature is considered. To this distance may be added the further advantage gained by a good height of receiving antenna. The distance in miles to the optical horizon, $D_o = 1.23\sqrt{h}$, where h represents the height of the antenna in feet above the surrounding ground. The distance to the radio horizon, D_R, where the bending of the radio energy about the earth's curve is considered, may be expressed by the formula $D_R = 1.4\sqrt{h}$. These simple formulas are modified, however, by local irregularities in the terrain. Also, there are other propagation characteristics of the troposphere and occasional E layer skywave signals and F_2 layer skywave signals, which influence the service range and the interference range of television stations.

Fortunately 90 percent or more of the area surrounding most cities or metropolitan regions using television are relatively free of ghost conditions or serious shadow conditions and therefore television reception is available at a quality not appreciably less than that obtained in an ideal receiving location, which in turn provides approximately equal horizontal and vertical resolution of 525-line system with a contrast range of 30 or more in ratio of brightness of the most intense areas to the blackest areas.

Television relay services may maintain a very high quality of transmitted picture, since one may choose the location of both transmitter and receiver along the relay paths and since highly directive antennas minimize the spurious type multiple signals.

12-27. Receiver Installation Practice—The home installation of a television receiver, in a reasonably strong signal area, involves only a few major considerations, such as a suitable site for the antenna, convenient placing of the transmission line, and location of the receiver in a spot where reasonable freedom from direct sunlight may be expected. The best results from a viewer's standpoint are obtained where subdued illumination is available in the room but where no direct light, either natural or artificial, falls on the cathode-ray tube. Viewing is much less tiresome to the eyes if a certain amount of subdued lighting is retained in the room.

In areas where weak signals are prevalent, more time, care, and expense are required to obtain a suitable picture. Usually, this problem entails a detailed study of the location and a field strength meter with a collapsible antenna proves invaluable in the selection of the permanent antenna site. The study of standing wave and multipath conditions is materially aided through the use of such a meter. Generally speaking, the higher the antenna, the greater the received signal. The use of a preamplifier will, of course, build up the signal but at the same time it usually increases the objectionable noise in the same ratio.

When a convenient location has been chosen for the receiver considering the lighting problem, the transmission-line route is chosen to the antenna location, either on the roof, in a nearby tree, or out a window having the best probable exposure toward the desired television stations. Because of the high carrier frequencies involved and the wide band widths utilized, it is desirable to employ a low-loss transmission line, particularly for the higher frequency television channels. However, where high signal strengths are available quite satisfactory reception may be obtained through the use of a simple twisted-pair transmission line or even a simple antenna right in the room near the set. In general, however, best freedom from local disturbances, such as ignition interference and domestic machines, is assured by an outdoor antenna installation. Since the frequencies of television channels extend all the way from 44 mc to 216 mc, it is desirable to utilize one antenna for the lower group of channels from 44 mc to 88 mc and another antenna from 174 mc to 216 mc. However, where the signal levels are high and the orientation is favorable, a single nonresonant antenna will pick up sufficient signal from all stations. If the signal levels are very low, it may become desirable to use a relatively high-gain antenna for reception, with possibly three or four different antennas to cover, say, eight or ten desired stations. Figure 12-78 shows a typical horizontal folded-dipole receiving antenna suitable for the channels from 44 mc to 88 mc. Figure 12-79 shows a type of duo-band receiving antenna which affords good reception on all television and F-M channels.

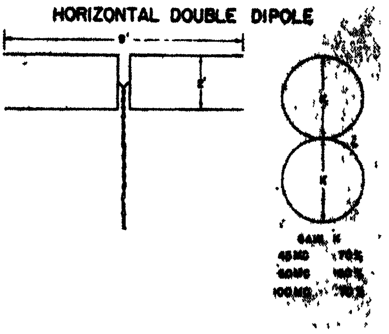


Fig. 12-78. Typical receiving antenna.

A picture received over the air will, in general, be somewhat inferior in comparison to a picture viewed directly over a station monitor. If the receiver itself is in good adjustment and a broad-band antenna and transmission line is used, the radio transmission will provide a picture of approximately equal horizontal and vertical resolution, as indicated by a test pattern such as that illustrated in Figure 12-24. However, a weak signal at the receiver necessitates high sensitivity of the set and high amplification of the signals. Thus a condition sometimes referred to as "snow" is visible on the pictures, representing tube noise and interfering signals caused by man-made static. Atmospheric static is practically absent at television frequencies. The presence of this noise, or snow, as it is commonly called, decreases the resolution of the picture by altering the original wave shapes. The noise also substantially decreases the timing precision of the synchronizing waveforms, resulting in a slight displacement of lines and fields and reduces the average over-all crispness and resolution of the pic-

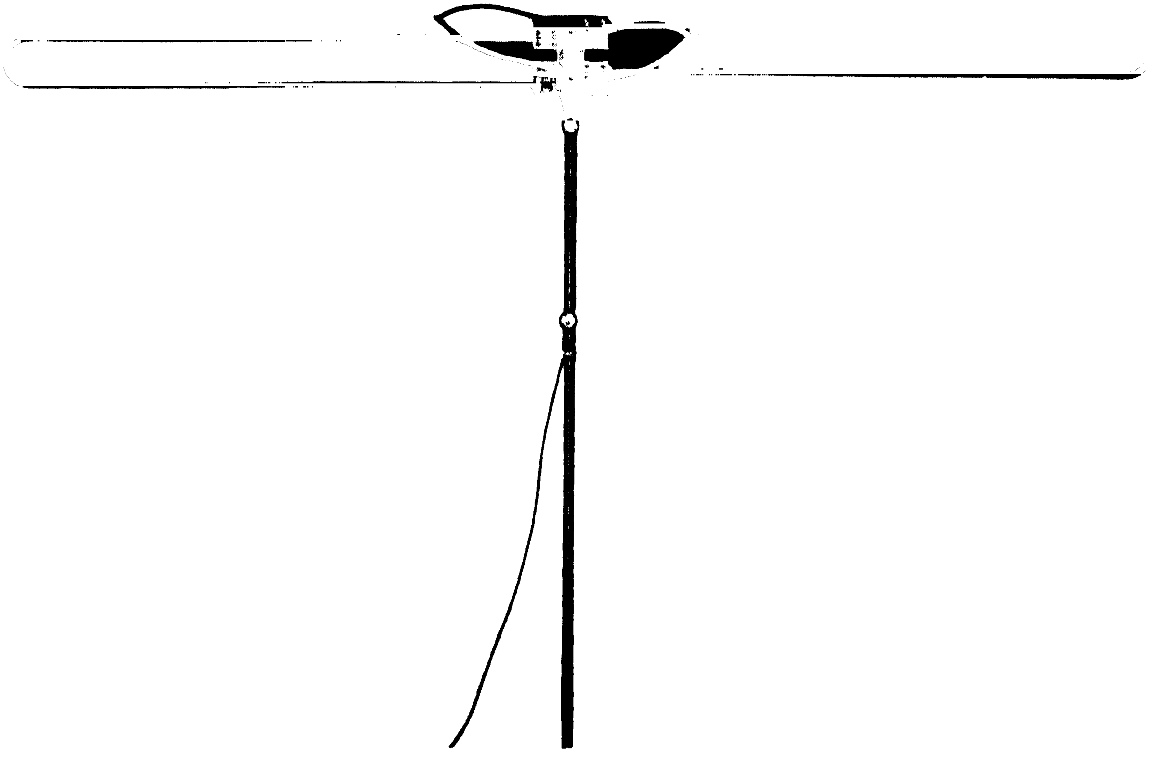


Fig. 12-79. Duo-band receiving antenna.

tures. As a rule, these noisy pictures are experienced beyond the 500 microvolt per meter contour of the television station, thus requiring that television receiver installations beyond this contour must be made with considerably more care than is normally required.

An antenna directed toward the transmitting station usually provides the best results; however, multipath conditions producing ghost patterns are often found, usually in a city where large buildings, water tanks, etc., reflect the transmitted signals. Where such multipath conditions exist, the television receiver antenna may be oriented so that the unwanted signal is minimized. Often it is possible to eliminate completely the ghost by this method. In isolated cases, it is possible to maximate the antenna on the ghost signal, minimize the direct signal, and obtain a suitable picture.

In some areas it will be found that only d.c. is available for operating power. Satisfactory installations can be made, however, by using a rotary converter to generate 115-volt a-c power at approximately 60 cycles. Since the vertical synchronization signals are transmitted directly from the broadcast station, it is not necessary that the receiver power supply operate in exact synchronism with the transmitter power supply. In some receiver installations, where the power frequency is too far removed from that of the transmitter, it may be necessary to provide additional magnetic shielding since the receiver power transformers may set up a fairly strong magnetic field which causes the picture to weave back and forth. This weaving is caused by the different power frequencies and the rate of weave is proportional to the frequency difference of the power lines.

Where a television receiver is located near the transmitter and where no serious obstacles intervene, it is quite satisfactory to install an indoor or attic antenna. However, for distances between ten and thirty miles from the transmitter the signal strength is usually not sufficient for an indoor installation and thus it is customary to erect the antenna on a pole above the roof. At extreme distances it is advantageous to use a complex antenna which has some voltage gain greater than that of the simple dipole. These antennas may take the form of rhombics, several-element Yagi arrays or even stacked arrays. Usually such an array is most efficient over a limited number of channels and thus when a receiver is installed, say, 70 miles from the stations, it may be necessary to use two or more separate antennas.

Receiving circuits have been improved to such an extent that interferences from ignition, motor sparking and other types of man-made static are not nearly so serious as in the early days of television. However, there are still many sources of trouble which must be avoided in order to secure excellent television performance. Some of these are radiation from local oscillators of other receivers, co-channel interference from other television stations assigned on the same frequency but in a distant city, effects of diathermy, and the spurious receptions of other radio services.

Adjacent television channels are not assigned in the same service area. Also the separation between cities having co-channel assignments is usually the order of 150 miles so that the rural area around one city can be provided with coverage without serious interference from the other city. Scarcity of channels has made it necessary in some instances to reduce this spacing with a consequent decrease of the service range of the stations.

One of the most difficult installation problems arises because of the diversity of directions from the receiving location to the transmitting antennas of the several stations it is desired to receive. An antenna satisfactory for one station may prove to have a weak or ghosty signal from the next desired station, requiring multiple installations. In large apartment houses and hotels this problem is handled by a master distribution system which employs an adequate number of antennas to secure good pictures from the several stations, and then provides amplifiers and multiple outlets to a large number of subscribers.

A signal strength in excess of 5000 microvolts per meter will provide excellent service, even where a moderate amount of industrial and ignition noise is present. Five hundred microvolts per meter is sufficient for residential and rural areas. Where co-channel interference is not a limting factor, there are many receivers giving quite acceptable performance to their owners at distances of 60 to 100 miles and where the signals at the receiver terminals scarcely reach 200 microvolts.

However, the ultimate acceptability to the receiver owner rests mainly on choice of good program material and smoothness of technical operation of the entire broadcasting staff.

CHAPTER 13

MARINE RADIO EQUIPMENT

The marine radio equipment described in this chapter will be found on ships of the United States Maritime Commission and other operators of merchant and tank ships. The Mackay FT-106 and the RMCA 4U marine radio units, described in the forward part of the chapter, represent a new approach to the design of marine radio installations. This design has been frequently referred to as "packaged" equipment, inasmuch as each of these units include all the essential transmitters, receivers, auto alarms, power supplies, control apparatus, and associated equipment, assembled in a compact steel enclosure of the console type. A basic consideration in the design of these units was a physical construction capable of installation in a minimum of time. The various components are assembled and wired at the factory in their respective frames. Interframe cables are supplied to facilitate interconnections between frames during installation.

The "packaged" type of marine radio installation has the added advantage that all components and operating controls are standardized with regard to their position. This simplifies and expedites the training of installation, operating and maintenance personnel.

The descriptions of these and other marine radio equipments in this chapter have been taken, for the most part, with little change from the instruction manuals supplied by the manufacturers.

13–1. Mackay Radio FT–106 Marine Radio Unit—The FT–106 marine radio unit consists of three steel cabinets each 72 inches high, 29 inches wide, and 19 inches deep. Three cabinets are supplied so as to permit passage through doors and hallways and otherwise to facilitate handling. Lifting eyes are attached to the top of each unit, permitting the units to be hoisted without difficulty. The three cabinets are bolted together after being placed in position, forming an assembly 72 inches high, 87 inches wide, and 19 inches deep. The assembled transmitter complies with the requirements of the F.C.C., the Bureau of Marine Inspection and Navigation, and the U. S. Maritime Commission. Doors provided on the sides and front of this unit permit access to the equipment within the cabinets. The operating shelf extends the full width of the unit providing a surface 87 inches by 18 inches with the message compartments immediately to the rear of the shelf. The doors of the unit are reinforced and are held in place by captivated thumbscrews. Each panel-mounted component, with the exception of the antenna and grounding switches, is arranged to be removed from the front for adjustment and part replacement if required. Controls for starting and stopping equipment, switching the various units, and charging all batteries are located within easy reach of the operator. Generators and starters are treated for vibration and electrical noise and placed in the lower section of the unit where they are accessible from the front. Storage space for spares is also furnished in the lower section. A ventilating fan within the cabinet prevents overheating of components. Emergency illumination of all controls, fuses and emergency power equipment is provided. Special precautions have been taken in the design and manufacture of the equipment to render it moisture proof and resistant to corrosive action from salt sea atmosphere. All ferrous panels are plated to prevent rust. Metal panels in the vicinity of radio frequency inductors are copper plated to prevent losses.

13–1a. Components of FT–106 Marine Radio Unit—The individual components which comprise the FT–106 Marine Radio Unit are as follows:

1. *Main and Emergency Radio Transmitter 155AY* provides for telegraphic transmission using the ship's power supply or its own battery power in case of failure of the ship's power. The transmitter, together with its battery controls, main motor generator, and starter, is assembled in the center cabinet of the marine unit. The transmitter panel, hinged at the bottom, swings outward, giving access to all components. The emergency motor generator is located in the base of the right hand cabinet of the marine unit.

The 155AY transmitter provides operation on any eight pre-set frequencies in the intermediate range of ship frequencies (350–500 kc). These frequencies may be either master-oscillator or crystal-controlled, as chosen by the operator. Switching is provided to permit operating as a main transmitter using power from the ship's line or as an emergency transmitter operating from batteries. As a main transmitter, the 155AY provides an output of more than 200 watts CW (A–1 emission) and more than 300 watts ICW (A–2 emission).

The power output using the 24-volt emergency power is in excess of 40 watts CW (A–1) and 50 watts ICW (A–2). Satisfactory communication is therefore assured, even when the ship's power is not available. The signals using either power source are clean cut and sharp, and the modulation, which is nearly sinusoidal, is readily distinguishable through heavy interference or atmospheric noises.

An IF-HF switch on the 155AY panel provides a means of using the rectifier and filter components

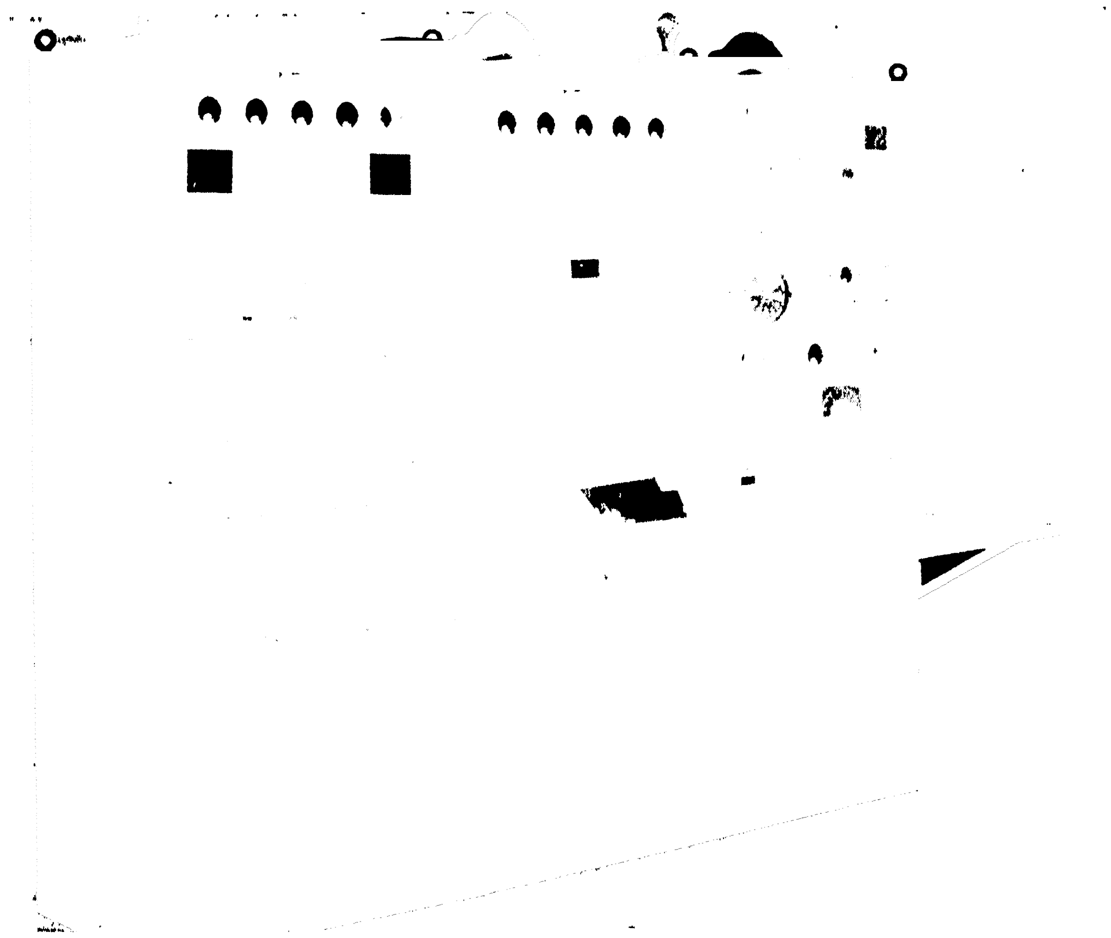


Fig. 13-1. The Mackay FT-106 marine radio unit.

of the 155AY to provide a plate voltage for the 167AY high-frequency transmitter. This switch also provides a means for connecting the filament transformer in the high-frequency transmitter to the filament supply winding of the main motor generator whenever the switch is in the position which transfers plate power from the tubes in the 155AY transmitter to the tubes in the 167AY transmitter.

The keying of the 155AY transmitter is accomplished by a keying relay which makes and breaks the input circuit of the rectifier power transformer. This relay operates from the 115-volt d-c line or from the 24-volt battery, depending on whether main or emergency operation is employed. An additional set of contacts on this relay keys the oscillator of the 167AY transmitter.

2. *Radio Transmitter 167AY* provides telegraphic communication on all frequencies between 2 and 24 mc. In the FT-106 marine radio unit, this transmitter is provided with power from the rectifier which is included in the 155AY transmitter. Keying is accomplished using the keying relay of the 155AY which is in the primary circuit of the rectifier. An additional set of contacts on the keying relay keys the plate supply of the oscillator in the high-frequency transmitter, thus assuring no interference if break-in operation is desired.

The 167AY transmitter, which is located in the left-hand section of the marine unit, provides an output of more than 200 watts CW (A-1 emission) on any frequency between 2 and 16 mc and more than 150 watts between 16 and 24 mc. These frequencies may be either master-oscillator or crystal-controlled, as chosen by the operator. Provision is made for ten crystals, which, through harmonic operation, will provide up to forty crystal-controlled frequencies.

The front panel of the transmitter is hinged at the bottom, thus allowing the front panel to swing outward, giving access to all components within the transmitter.

3. *Auto Alarm Receiver 101B and Auto Alarm Selector 101B*, both of which are mounted on the panel at the upper right of the right-hand section of the Marine Unit, maintain a radio watch when the operator is off duty. The device is receptive to

all modulated radio signals transmitted on the calling and distress frequency of 500 kc (600 meters) but is so arranged that it will reject all combinations of code signals except those composing the international distress call. Alarm bells on the bridge, in the radio room, and in the operators' quarters announce the reception of such signals. The receiver and selector are mounted on separate chassis, which swing outward, permitting access to all parts. The radio room alarm bell is mounted on the back of the Unit, while the alarm pilot lamps are placed directly in front of the operator, on the front panel. The power supply unit for the auto alarm is located on the back panel, behind motor generator 120. An automatic distress transmitting device, for automatically keying the transmitter, is also incorporated as a part of the auto alarm.

4. *Radio Receiver 128AV* is placed just above the operating shelf on the right side of the Marine Radio Unit where it is within easy reach of the operator when he sits in front of the typewriter. This receiver uses 6-volt storage batteries for filament power and includes a rectifier connected to the ship's a-c line to provide plate supply for the tubes. Switching is provided to permit transfer to "B" batteries included in the Unit if the ship's power should fail.

This receiver covers the range of 15 to 650 kc in four bands. It is of modern design having a full-vision, illuminated, directly calibrated scale with a single knob control. Absolute freedom from images or false signals is obtained. Stability under vibration and tuning of high practical order has been secured in the design of this receiver. The receiver is completely removable from the front of the cabinet. The connecting leads between the receiver and the Unit are sufficiently long to permit servicing the receiver on the operating shelf of the Unit. The receiver may be removed completely by removing three plug-in cords. This receiver may be connected to operate from the main, emergency, or the auxiliary antenna.

A lead has been run from the audio output circuit of the 128AV receiver to the TIME CHECK switch of

FIG. 13–2. Mackay FT-106 marine radio unit with front panels open.

the Marine Radio Unit from which point a cable is run to a jack located near the chronometer in the chart room to permit easy checking of the chronometer.

5. *Radio Receiver 123BX* is an emergency receiver utilizing a crystal detector. This receiver, which covers the intermediate frequency range of 350 to 550 kc, is immediately usable in case of failure of the main receiver. It is arranged to be used with either the main, emergency, or auxiliary antenna.

6. *Radio Receiver SLR-F* is an eleven-tube superheterodyne covering the frequency ranges of 80 to 560 kc and 1.9 to 24.0 mc in five bands. This receiver is located in the left-hand section of the Marine Radio Unit, immediately below the 167AY transmitter, in a position where it is easily accessible to the operator.

This receiver, which obtains its power from the ship's a-c line, may be removed from the panel on which it is mounted by removing four thumbscrews. The leads between the receiver and the Unit are long enough to permit servicing the receiver placed on the operating shelf. These leads are of the plug-in type, making it easy to remove the receiver completely if the need should arise.

A lead is run from the audio output circuit of the receiver to the time check switch of the Marine Radio Unit, making it possible to obtain time check signals on high frequencies.

A doublet antenna is provided with the Marine Radio Unit for connection to this receiver, which is not connected to any of the other antennas.

7. *Antenna Switch 107A* is located in the upper left corner of the right cabinet of the Marine Radio Unit. This switch and the grounding switch located immediately below it include all facilities for switching the antennas to the transmitters, receivers, and auto alarm, for grounding the antennas, and for connecting the dummy load to the 155AY transmitter for testing. A direction finder signal lamp is included on the antenna switch, and the necessary interlocks to assure accuracy of the direction finder calibration are provided. All high voltage parts are located behind the panel, providing safety for the operator.

8. *Battery Charging and Control Circuits* are placed on a panel in the right cabinet of the Unit, just above the 128AV and 123BX receivers. Two sets of batteries are provided for both the auto alarm and the 128AV receiver, and the switching facilities permit charging of one set while the other is in use. All charging resistors are placed within the cabinet, a ventilating fan serving to exhaust the heat generated. This fan, which operates at two speeds, is automatically started when any of the charging switches are thrown, the speed being proportioned for the heat to be dissipated. A thermostat placed above the charging resistors will automatically open the main charging circuit in case of failure of the fan leading to excessive heating, thus preventing possible damage to internal components. A d-c line voltmeter is also placed on this panel providing an indication of line voltage and polarity at all times.

9. *Lights and Miscellaneous Equipment.* Emergency lights operating from the 24-volt emergency battery are arranged to illuminate all controls on the front panel as well as the emergency generator, fuses, "B" batteries, and terminal equipment.

A convenience outlet for a soldering iron or extension light is located in the right-hand section of the Unit. This provides 110 volts d-c.

Panel space for a radio clock (not ordinarily furnished with the equipment) is provided in the right-hand section immediately below the antenna grounding switch.

At the rear of the lower section of the right hand cabinet are located "B" batteries for emergency operation of the auto alarm and 128AV receiver. These batteries may be placed in position from the front of the equipment and may be reached for periodic testing by opening the door on the right side of the Unit.

To the left of the right-hand bottom section are the fuses for charging circuits, emergency light circuit, and the auto alarm power supply circuit. The line voltmeter is connected across the last mentioned circuit, while the ventilating fan operates from the charging circuit. Below the fuses is the main terminal block to which are connected receiver batteries, auto alarm batteries, and remote auto alarm lights and alarm bells.

Below the main terminal block is a two-terminal block for connecting to the direction finder control and signal circuit. To the right of this are two fuse blocks for the a-c ship's line and the direction finder battery charger.

Toward the front of the right-hand bottom section is the main disconnect switch. This switch is of the enclosed safety type which does not expose the operator to shock. It is used to disconnect completely the 110 volt d-c ship's supply from all equipment. Below this switch is placed the fuse block for the 24-volt emergency battery. The feeders from the ship's power board and the emergency batteries are connected at these points.

The two generators in the bases of the right-hand and center sections of the Unit are mounted on cushion supports which in turn are attached to separate base plates. In order to remove a generator for inspection, replacement, or repair, it is only necessary to remove the four screws which hold the small base plates to the channel frame of the Marine Unit and slide the machine out.

The time limit starter for the main motor generator is located to the left of the machine in the rear of the center section of the Unit. The starting relays for the emergency generator are placed inside its terminal box.

The wiring details as they apply to particular equipments will be covered in the individual descriptions that follow.

13–1b. Mackay Radio Transmitter 155AY (Component of FT-106 Marine Radio Unit)— Radio transmitter 155AY is designed especially for use as a main and emergency transmitter on cargo vessels. It provides for quick change to any one of eight frequencies in the intermediate frequency range of 350 to 500 kc (857 to 600 meters). Automatic break-in operation is received by means of the keying relay which transfers the antenna from "Send" to "Receive" when the transmitting key is opened. The transmitter will deliver in excess of 200 watts CW (A–1) and over 300 watts ICW (A–2) into the average ship's antenna when operating from the ship's supply of 115 volts d-c. Emergency operation of the transmitter from the 24-volt emergency battery provides an output in excess of 50 watts ICW (A–2) on all frequencies. CW (A–1) output of approximately 40 watts is also available. Emergency operation for a period of six consecutive hours is provided as required by the Federal Communications Commission. The transmitter is designed to operate into an antenna of from 1 to 14 ohms resistance, and from 500 to 1500 $\mu\mu$f equivalent capacitance. Modulation at approximately 720 cycles is obtained for ICW. The modulation is nearly sinusoidal and is greater than 85 percent. Figure 13–3 shows a wiring diagram of the 155AY transmitter.

Switching facilities are provided for charging and discharging the emergency batteries, for connecting the transmitter to either the main or emergency generator, and for starting either motor generator. Meters are placed in the battery and transmitter circuits for determining all important and essential conditions of operation.

1. *Frequency Stability.* The maximum frequency deviation from a preset value will in no case exceed ± 0.1 percent due to all causes, i.e., antenna tuning, temperature variation, line voltage variation, vibration, plate and filament voltage fluctuation, modulation, keying, etc. The precision to which a frequency can be set depends only on the precision of the frequency standard used for comparison.

2. *Motor Generators and Starters.* The main motor generator (motor generator 116A) is located in the lower compartment of the center section of the Marine Unit, mounted on rubber vibration absorbing cushions. This machine is a single unit, two ball-bearing, drip-proof motor alternator. Approximately 75 volts at 120 cycles is taken from slip rings on the motor to provide filament power. The plate power, which is provided from the alternator end of the machine, is 200 volts at 720 cycles. The machine is designed to operate the transmitter satisfactorily with line voltages ranging from 90 to 120 volts. A field rheostat located on the front panel of the 155AY transmitter controls the 720-cycle output voltage of this machine. Filters are included in the terminal box and at the generator and motor brushes to reduce electrical noise interference to near-by receivers over the operating range of frequencies. The starter for this motor generator is mounted on the rear panel of the Marine Unit in the center section, just behind the generator itself. This starter consists of an escapement type device with suitable starting resistance to bring the motor up to speed without placing an excessive load on the d-c line. In addition, this starter is equipped with a pair of auxiliary contacts which function as a time delay of 15 seconds to prevent premature application of plate voltage to the mercury vapor rectifier tubes when starting the equipment.

The motor generator used with the battery supply (motor generator 120A) is of the identical size and construction as the main machine described above. This motor generator produces 120-cycle power equivalent to that of the main machine, and 720-cycle power at approximately 100 volts, as determined by a field resistor in the terminal box of the motor generator. The motor and generator field are wound to operate on 24 volts. A starting circuit, consisting of two relays and a series resistance, cause the motor generator to come up to speed smoothly and without excessive current inrush. A time delay circuit consisting of a relay and a thermal delay strip prevents the application of the emergency power until the rectifier tubes have heated. This time delay circuit is mounted on the right rear of the transmitter base.

Both generators are mounted on separate metal pieces to which are attached the generator cushions. If it is desired to remove a generator for service or inspection, it is necessary only to detach the bolts which secure the two independent pieces to which the cushions are attached, and slide the machine forward.

3. *Power Supply and Power Equipment.* Mounted on the base of the transmitter are the necessary transformers, rectifier and filter components for converting the 720-cycle output of the generators to the correct voltages and currents for operating the vacuum tubes. The transmitter power supply consists of a single-phase, full-wave rectifier, using mercury-vapor tubes, and a single section filter, providing plate power for the master-oscillator-buffer tube, intermediate and power amplifier stages. A small half-wave rectifier tube and single-stage filter provide plate power for the crystal-oscillator stage when that is used. This latter rectifier is connected in a bridge circuit providing reduced voltage when the key is raised. This voltage is just enough to keep the crystal in oscillation, thereby assuring clean-cut signals even with crystals which may be slow starting.

A filament transformer, a power-factor-correcting condenser, and a modulation transformer to plate-modulate the final stage are also mounted on the base of the transmitter. A simple wave filter is provided to insure that the modulating voltage is essentially sinusoidal.

4. *Method of Signaling.* Keying of the transmitter is accomplished by means of a break-in relay which is operated from the 115- or 24-volt supplies, depending upon whether main or emergency operation is employed. The power contacts of this relay break the power input to the plate transformer of the mercury vapor rectifier, and through the back contacts connect the bridging circuit to the small rectifier when the key is released.

Contacts in the antenna circuit of the transmitter transfer the antenna to the 128AV receiver whenever the key is released. An additional set of "make" contacts on this relay provides a means for keying the plate supply of the oscillator in the 167AY transmitter.

For ICW operation the 720-cycle voltage is filtered to produce a good wave form, and is applied to the primary of the modulation transformer which plate modulates the final stage in a series modulated circuit. Change from CW to ICW operation is accomplished by the CW-ICW switch at the right center of the transmitter panel. This switch closes the circuit from the generator to the primary of the modulation transformer in the ICW position. The circuit is so arranged that no power is applied to the modulation transformer unless the keying relay is closed.

The transmitter functions in an identical manner regardless of whether the main or emergency motor generator is used. The panel switch marked POWER connects the 120- and 720-cycle power of whichever machine is in use to the transmitter components, and transfers the keying relay circuit to the proper source for the generator in use. The battery-driven emergency generator is arranged to provide but one half of the 720-cycle output voltage of the main machine, but the operation of the transmitter is identical in either case.

5. *Type of Circuit.* Radio-frequency circuits of the 155AY transmitter shown in Figure 13-3 include a crystal oscillator, a master-oscillator buffer, an untuned intermediate amplifier, and a final amplifier. The crystal oscillator employs a 6L6 tube in a tuned grid untuned plate circuit with plate supply coming from a 1V tube in a half-wave rectifier circuit. This rectifier, which is disconnected when the XTAL-ELEC switch is in the ELEC position, provides a continuous d-c supply for the operation of the crystal-oscillator circuit during the periods when the transmitter is running. This separate supply circuit is provided to eliminate the lag present when an oscillator using crystals in this frequency range is keyed. Key-up interference is reduced to a low level by means of a bridging resistance connected to the back contacts of the keying relay, which decreases the voltage applied to the oscillator during the key-up periods, yet maintains weak oscillations. When the key is closed, the voltage applied to the crystal oscillator circuit is increased to a working value, but as the crystal is already oscillating, no time is required to secure normal crystal oscillator operation.

The second 6L6 may be used as a buffer amplifier stage for the crystal oscillator, or as a master oscillator. As a buffer amplifier stage, the circuit is that of a tuned plate untuned grid type of amplifier. The plate tuning which is preset for the eight frequencies on which the transmitter is to operate is accomplished by taps on the plate coil and eight trimmer condensers. An eight-position switch located on the left center of the transmitter panel serves to select the proper crystal, the crystal oscillator grid inductance, and the tap and condenser of the buffer amplifier.

When the XTAL-ELEC switch is in the ELEC position, the grid circuit of the second stage is connected to a coil located within the plate coil of the stage, forming an untuned grid tuned plate oscillator of the inductive feedback type. The eight trimmer condensers of the plate circuit of the master-oscillator buffer stage and the XTAL-ELEC switch are located on a vertical panel hung under the left side of the transmitter shelf.

The intermediate amplifier employs a single F-123-A tube with cathode bias to protect the tubes in case of loss of excitation. Its output is impedance coupled by means of suitable chokes and blocking condensers to the grids of the final amplifier tubes.

The final amplifier employs two F-123-A tubes in parallel. These are also protected by means of cathode bias. The plate circuit of the final amplifier contains a radio frequency transformer for transferring energy from the tubes to the antenna circuit. The primary of this transformer presents a high impedance, since it is roughly self-resonant in the middle of the band of frequencies over which it is required that the transmitter operate. The secondary of this radio frequency transformer is wound on a ceramic form and consists of a few turns with frequent taps. This provides for adjusting to various antenna resistances. This transformer is located at the right side below the shelf of the transmitter. Its secondary is connected in series with the antenna loading coil.

The antenna loading coil is located on the right front corner of the transmitter shelf and consists of a tapped coil with a rotor which is controlled by the knob marked "Antenna Tuning" at the upper right of the transmitter panel. A switch at the rear of the coil, actuated by the rotor, is part of the coil assembly. This switch changes the inductance by means of changing taps on the stator winding as the rotor passes through the 180° position. An auxiliary contact on this switch opens the power supply so that the switch is not permitted to change

the taps while radio frequency energy is in the antenna circuit. By this means, any antenna whose equivalent capacitance falls in the range of 500 to 1500$\mu\mu$f may be tuned without additional wave-change control.

A pair of contacts of the keying relay is inserted in the antenna circuit between the radio frequency transformer and the loading coil. These contacts serve to transfer the antenna from the "Transmit" to "Receive" position for break-in operation. A lead for the receiver antenna is brought to a stand-off insulator at the top of the terminal board between the center right hand frames of the Marine Unit. In order to protect against excessively high plate voltages and abnormal conditions of operation, a glass-enclosed gas-filled protective spark gap is placed at the high potential end of the radio frequency transformer primary and a high resistance in series with this gap limits the current upon discharge. The direct-current component of this current operates a relay of which the coil is in series with the limiting resistor. The contacts of the relay are in the keying circuit and open the power to the primary of the plate transformer upon discharge of the gap. In case of failure of the glass-enclosed protective gap, an auxiliary spark gap is located immediately below the glass cartridge. This auxiliary gap, which parallels that in the cartridge, will discharge and afford the necessary protection.

6. *Metering Facilities.* Five meters are located on the front panel of the transmitter. The left-hand meter of the panel, labeled CHG. CURRENT, indicates the rate of charge in the 24-volt emergency battery. The second meter, labeled PLATE CURRENT, indicates the cathode current of the different radio-frequency stages as chosen by the PLATE CURRENT switch on the upper left corner of the transmitter panel. The center meter labeled ANT. CURRENT, indicates the radio-frequency current at the ground end of the antenna circuit. The fourth meter, labeled FIL. VOLTAGE, indicates the voltage in the filament of the crystal oscillator stage. The right-hand meter, labeled BATT. VOLTAGE, indicates the voltage of the emergency batteries whenever the emergency motor generator is in operation.

7. *Switching Controls.* The power controls are placed above and between the filament and field rheostats near the bottom of the transmitter panel. To the left of the row of three switch knobs is one labeled POWER. The purpose of this control is to connect the transmitter to either the main or emergency generator. This switch controls the 120- and 720-cycle power leads. In addition, it connects the keying relay to work on 24 or 115 volts, as the case may be. It is on this switch that a seal is placed, if one is used, since with this switch sealed in the OFF position, neither the 155AY nor the 167AY transmitter can be used. The center switch, which is marked BATTERY, when thrown to the left or CHARGE position, places the emergency battery on charge, and when thrown to the START position connects the battery to the starting relay in the terminal box of the 120A motor generator, starting the machine. During charge, the current rate is controlled by a toggle switch below the BATTERY switch. This toggle switch, when in the upper or FULL CHARGE position, causes the battery to be charged at an 8-amp rate. When thrown to the lower or TRICKLE CHARGE position, the rate is 0.5 amp. During trickle charge, when the heat generated by the charger resistors is low, the fan operates at a low speed. When the battery is placed on full charge, the fan is run at the higher speed. This switch can also be used to control the rate of speed of the fan when the transmitter is in use, though under normal conditions, the lower rate of speed is adequate to discharge the amount of heat generated by the transmitter tubes and power components. The right-hand switch marked LINE, is placed in the 115-volt d-c line and, when thrown to the ON position, operates to start the main motor generator and connect the d-c line to the keying and field circuits.

On the lower left of the transmitter panel is placed a filament control for adjusting the filament voltage of all tubes. At the corresponding position on the lower right of the panel is the field rheostat which controls the 720-cycle power output of the main motor generator.

In a horizontal row above the power switch are three switches. The left switch is the FREQUENCY switch by means of which the proper one of the eight pre-set frequencies is chosen. The center switch, labeled IF-HF serves to transfer the filament and plate power from the 155AY transmitter to the 167AY transmitter. The right-hand switch selects either CW (A-1) or ICW (A-2) emission.

In the upper left corner of the transmitter panel is a switch for transferring the PLATE CURRENT meter to the different stages, and in the upper right corner is the ANTENNA TUNING knob, controlling the rotor of the antenna loading coil, described previously.

8. *Adjustment of Transmitter.* The power, modulating, and filament transformers are equipped with taps corresponding to the maximum generator voltage which would be obtained with various d-c line voltages. The average d-c supply voltage may be ascertained from an observation of the line voltmeter on the right hand section of the Marine Radio Unit, and the transformers adjusted in accordance with the following table:

Line Voltage	*Power Trans. Tap.*	*Modulation Trans. Tap.*	*Filament Trans. Tap*
110–120	0–255	0–225	0–73
100–110	0–235	0–208	0–60
90–100	0–210	0–190	0–60

Although the transmitter can be made to deliver full power at the voltage of the line over the above ranges of 90 to 120 volts, it is adjusted at the factory for 115-volt operation. Unless it is noted that the average voltage is less than 110 volts, no adjustment should be altered. If line voltage fluctuations are prevalent, the transformer taps must be set for the highest line voltage which will be experienced.

After the antenna has been erected and the equipment has been installed in accordance with the foregoing installation instructions, proceed as follows:

Place in the sockets in the base section of the transmitter two 866–A tubes and one 1V tube. Be sure to connect the plate caps on the 866–A tubes. In the two octal sockets on the shelf place 6L6 tubes, and in the three large sockets, F–123–A tubes. Note that voltage is indicated on the line voltmeter, and make sure that fuses are inserted in the transmitter and in the fuse clips for the 24 volt battery below the main line switch in the right hand section of the Marine Unit. Turn the POWER switch of the transmitter panel to MAIN and the IF-HF switch to IF. Place the BATTERY switch in the OFF position. Turn the LINE switch to ON. The main motor generator should start smoothly. Adjust the filament rheostat so that the filament voltmeter reads 6.3 volts. Allow the transmitter to run for fifteen minutes in this condition before pressing the key. This permits the mercury in the rectifier tubes to evaporate from the elements and envelope. This fifteen-minute warm-up period should be observed whenever new mercury vapor tubes are inserted in the transmitter. It should be noted that the ventilating fan is set in motion by the starting of the transmitter. This fan will operate only when the main motor generator is in use.

Open the transmitter panel to the halfway point which provides access to the antenna coupling transformer and the antenna tuning variometer. On the rear of the variometer is a switch which transfers the antenna circuit inductance from one value to another as the variometer is tuned through its range. The two leads from the switch must be connected to terminals on the variometer which will provide tuning over the entire frequency range for the antenna to be used. The variometer is equipped with three taps. The first is located on the upper end of the coil near the switch panel, the second at the lower end of the coil near the switch panel, and the third, or maximum inductance tap, is located at the lower end of the coil toward the front panel. In adjusting these taps, the leads from the upper switch terminal must be placed on the terminal which provides resonance at 500 kc at some point on the variometer dial between 0 and 100. This will be tap 1 if the antenna is 800-$\mu\mu$f capacitance or greater, tap 2 if the antenna capacity is less than this value. If the upper switch lead runs to the variometer tap 1, the lower switch lead should be placed on coil tap 2; and if the upper switch lead runs to coil tap 2, the lower should be connected to coil tap 3. When so arranged, resonance will be obtained on all eight frequencies at some point on the variometer dial.

The two leads which run to the taps on the coupling transformer (the ceramic form on the under side of the shelf directly below the antenna variometer) vary the loading of the amplifier tubes. The number of turns to be used will depend upon the resistance of the antenna. With the FREQUENCY switch on tap 6, corresponding to a frequency of 400 kc, the CW-ICW on CW position and the field rheostat turned clockwise all the way to provide full power from the generator, adjust the coupler taps until an amplifier plate current of 350 ma is indicated when the antenna is resonated with the ANT. TUNING knob. At 500 kc the amplifier plate current reading may be slightly higher than 350 ma and at 355 kc, it may be slightly lower. In adjusting the coupler taps, use an equal number of taps on each side of the center of the coil, if possible. If it is necessary to use one turn less than an equal, this turn may be removed from either side of center. It will be noted that when the CW-ICW switch is thrown to the ICW position, the amplifier plate current drops slightly, because of the reduction in plate voltage when the added load is imposed upon the generator.

With the PLATE CURRENT switch on the OSC position, the cathode current of the crystal oscillator and master oscillator buffer stages is read. If the transmitter is operating on master oscillator, there is no crystal oscillator cathode current; then the cathode current of the master oscillator buffer is read. With the switch on the IA position, the cathode current of the intermediate amplifier stage is read. This reading will vary with frequency, but will average about 70 ma over the frequency range and should in no case exceed 120 ma. With the switch in the third position, marked PA, the meter indicates the cathode current of the power amplifier stage. This reading will depend on how heavily the transmitter is loaded, but in no case should it exceed 380 ma. In normal operation, the switch is left in the third position marked PA where it acts as a guide for the operator making antenna adjustments.

With the CW-ICW switch in the CW position, check the adjustment of all frequencies using master-oscillator operation. If possible, this should be done using a heterodyne type frequency monitor. Tuning controls are located on a bracket hanging from the under side of the left edge of the shelf of the transmitter. Eight trimmer condensers act as vernier frequency adjusting devices. These are numbered to correspond to the position on the FREQUENCY switch with which they are associated.

The transmitter panel may be opened to the 45° position, giving access to the tuning condensers. The transmitter may be run in this position, with the plate voltage reduced by turning the FIELD RHEO fully counterclockwise. A pick-up loop for the heterodyne frequency meter will enable the operator to adjust all frequencies in this way. Note that when this is done, the power amplifier stage is operating without load. The plate voltage should be kept low to assure that the tubes are not damaged.

The frequencies have been set up at the factory as follows:

Frequency Sw. Position	*Frequency (kc)*	*Wave Length (m)*
1	500	600
2	468	640
3	454	660
4	425	706
5	410	732
6	400	750
7	375	800
8	355	845

If it is planned to operate the transmitter at frequencies widely different from those listed above it will, of course, be necessary to relocate the taps on the oscillator coil as well as adjust the vernier condensers after the proper tap has been chosen.

In adjusting to a frequency which requires a change of tap on the oscillator coil, remove the aluminum shield can, relocate the tap, soldering it securely to the new position, and *replace the shield before checking the frequency.* Sufficient taps have been provided on the oscillator coil to permit tuning the transmitter to any frequency between 350 and 500 kc. To lower the frequency, taps higher on the coil should be used.

If an absorption type wavemeter is used, the antenna must be resonated before the frequency is checked. This may be done by closing the transmitter, or by using a jumper to complete the antenna circuit. If the frequency is found to be a trifle high or low, the capacity of the corresponding trimming condenser should be increased or decreased slightly, and the antenna resonated before checking the frequency. Do not attempt to tune the oscillator to the wavemeter, as the maximum deflection of the wavemeter may result from resonance of the antenna circuit on other than the desired frequency.

The circuit employed for the crystal oscillator is one in which oscillations occur without a crystal in place, at a frequency somewhat lower than that of the crystal. For this reason, dummy shorting plugs should be placed in all crystal jacks for which crystals are not supplied. This will prevent "off frequency" operation if crystal operation is attempted on a frequency for which there is no crystal.

The frequency of self-oscillation in the crystal oscillator is very important to proper crystal operation and is controlled by the crystal oscillator grid inductance which is located on the rear of the front panel directly above the filament rheostat. The coil is provided with seven taps, counting from the left of the transmitter toward the center. These taps are wired to the frequency switch to cause the oscillator to function without crystals at a frequency between 5 and 10 kc lower than that of the crystal.

If it becomes necessary to employ a crystal in some particular crystal jack at a frequency widely different from that for which it is adjusted, the proper switch lead must be placed on the grid coil tap which will cause the circuit to self-oscillate at a frequency lower than that of the crystal.

Should the r-f voltage across the amplifier plate coil become dangerously high, a discharge will occur across the gap in the cartridge which is mounted on the shelf at the rear of the antenna variometer. This discharge causes a relay to operate, opening the keying circuit. This relay is of the slow releasing type, and after a period of approximately one-half second the relay releases, again applying power to the transmitter. Should the condition which has caused the excessive voltage across the plate coil be unchanged, a discharge across the cartridge gap will again operate the relay and open the keying circuit. This cycle of operation will persist until the condition is corrected. Under normal operation, the r-f voltage across the plate coil will be insufficient to result in a discharge of the gap, and the operation of the relay. Should the antenna be completely detuned under full power conditions, or the power input raised beyond the point of safe operation by incorrect transformer tapping or some other means, a discharge will occur at the gap, operating the protective relay and preventing damage to transmitter parts. The additional gap beneath the cartridge will function, should the cartridge become broken or inoperative.

Having checked the above, turn the LINE switch to OFF. Turn the POWER switch to EMERG position. Turn the BATTERY switch in the center of the panel to START. The motor generator in the base of the right-hand section should start smoothly. The filament voltmeter may read slightly less than with main power. Adjust the filament rheostat for 6.3 volts. Turn the CW-ICW switch to ICW position. (Normally only ICW will be used for emergency operation.) No adjustment should be made to any circuits since those made for main operation will be correct. If other than the currents indicated (in the tabulation provided are obtained, check the a-c output of motor generator 120A. (Between ground and terminal 21 of the interconnecting blocks between the right hand and center frame of the Marine Unit), adjust the variable field resistor (R16 of RC-2922-14) in the terminal box of motor generator 120A to obtain 100 volts across these points. This adjustment has been made in the factory and should not be necessary in the field. During the above adjustments, the battery voltage meter at the top right of the transmitter panel should read 24 volts. Should the battery voltage be higher or lower, readings may vary.

Throw the BATTERY switch to CHARGE position. If the toggle switch below it is in the TRICKLE CHARGE position, the CHARGING CURRENT meter at the top left of the panel should read .5 amp, and the ventilating fan should operate at slow speed. When the toggle switch is thrown up to FULL CHARGE the meter will read 8 amperes, and the fan operate at increased speed. During operation of the transmitter, or at any time that the charger is not in use, this toggle switch should be kept in TRICKLE CHARGE position to prevent operation of the fan at high speed when the transmitter is operated. Under conditions of extremely high ambient temperatures, it may be desirable to run the fan at high speeds when the transmitter is operated, in which case the toggle switch may be left in FULL CHARGE position, but this condition represents the unusual.

9. *Operation of Transmitter.* Except when it is desired to use the battery power, the POWER switch on the panel should be kept in the MAIN position. To place the transmitter in condition for main operation, throw the LINE switch to ON position. The main motor generator at the base of the center section of the unit will come up to speed. Adjust the filament rheostat until the filament voltmeter reads 6.3 volts. Set the FREQUENCY switch on the position corresponding to the desired frequency of operation (Position 1 for calling purposes). After a period of approximately fifteen seconds, depress the telegraph key and resonate the antenna by adjusting the antenna variometer until maximum current is indicated on the ANT. CURRENT meter. If the position of the antenna variometer has been listed on the card attached to the front panel, the variometer may be adjusted to the prescribed dial reading at the same time the frequency switch is adjusted. For normal operation, the field rheostat should be set at a point where 300 ma is indicated on the PLATE CURRENT meter when reading the current in the final amplifier circuit (PLATE CURRENT switch in PA position). The transmitter may be safely operated at full power or the power may be reduced to one-half normal output if desired by adjustment of the field rheostat. It is poor practice to use more power than is required to effect satisfactory communication.

CW or ICW may be obtained by throwing the switch so labelled to the proper position. The power output of the transmitter, for any given field rheostat adjustment, is greater when operating ICW than when CW is used. Should the protective relay operate during adjustment of the transmitter, it is an indication that adjustments are incorrectly made. If the power input is dangerously high, or the antenna circuit detuned, disconnected or grounded, the relay may operate whenever the key is pressed. Correcting the condition will cause the relay to cease operating. The cartridge associated with the protective relay or the gap beneath it should never be tampered with. In case of failure or destruction of the cartridge, the gap beneath it will provide protection, but the cartridge should be replaced at the first opportunity. Frequency changing is accomplished by setting the frequency switch to the position representing the desired frequency and adjusting the antenna tuning to obtain a maximum antenna current. If the plate current exceeds 350 ma, the plate voltage should be dropped by means of a field rheostat.

It will, of course, be necessary that the 107A antenna switch and the grounding switch be in the proper positions whenever the transmitter is operating. The i-f transmitter may be operated into either the main or emergency ship's antennas, depending upon which position the antenna switch is turned to. The grounding switch must be in the ungrounded position, i.e., with the handle pushed in.

10. *Emergency Operation.* To place transmitter 155AY in operation from the emergency battery, turn the POWER switch to EMERG and the BATTERY switch to START. The CW-ICW switch will normally be in the ICW position. When the BATTERY switch is turned to the START position, the emergency motor generator in the right hand section of the Marine Unit will come up to speed. Adjust the filament voltage to 6.3 and after waiting fifteen seconds for the time delay to function, press the telegraph key and resonate the antenna following the same procedure as used in main operation. The output will be less than with main power, but the operation is in no way different.

It is possible to cause both generators to run simultaneously by having the LINE switch in the ON position. No harm is done by so doing. There is no point in this procedure, however, as but one machine can be used at a time. It should be carefully ascertained that the BATTERY VOLTAGE meter does not read when the emergency supply is not in use. This meter reads only when the BATTERY switch is in the START position. If the meter should read at any other time, repairs should be made immediately, since the drain on the batteries by the meter may impair emergency operation, should it prove necessary.

11. *Testing with Dummy Antenna.* A dummy antenna load consisting of a condenser and a resistor has been built into the Marine Radio Unit for testing the 155AY transmitter. This dummy load is connected to the transmitter by the antenna grounding switch. With the antennas grounded, the load is connected to the 155AY transmitter. This dummy load is designed to permit testing the emergency operation of the transmitter. It is provided with a spark gap on the condenser terminals. This gap will break down when the voltage across the condenser becomes too high, thereby detuning the transmitter if excessive power is provided to the dummy load. In this way, no damage can result through operation of the main transmitter with the dummy load. The method of operating the transmitter with this load is identical with that used with the actual ship's antenna except, of course, the setting of the antenna variometer will normally be different.

12. *Precautions to Be Observed.* Since the voltages within the transmitter during operation are

dangerous to human life, great caution should be observed when the panel is open for making internal adjustments. The only internal adjustments which may be made with the transmitter energized are the setting of the 8 trimmer condensers, the controls of which are at ground potential, and the position of the XTAL-ELEC switch. The motor generators should be shut down whenever anything else within the transmitter is to be touched. If possible, the main line switch should also be open.

In first placing the mercury vapor tubes in operation, they should be allowed to run with filaments lighted at normal voltage for fifteen minutes before applying plate voltage, in order to make sure that all the liquid mercury which has been deposited on the electrodes of these tubes during shipment has been vaporized. This precaution should be observed whether the tubes are new or have been on the shelf for any period of time.

The filament voltmeter should not be allowed to drop below 6 volts with the key down and the transmitter adjusted for operation. The voltage may be adjusted to 6.5 volts with the key up and operates normally with the filament voltmeter reading 6.3 volts key down. If the filament voltage is allowed to drop below 6, rapid deterioration of the rectifier tubes results. Premature failure of the rectifier tube usually occurs from low filament emission caused by under voltage or through applying plate voltage too soon after lighting the filaments. Contact on the motor stator prevents the application of plate power until about fifteen seconds after the START switch is thrown from main operation and a special time delay relay circuit provides this delay when the emergency power is employed.

13. *Maintenance of Equipment.* The commutators and slip rings of the motor generators should be kept clean and free from dirt or grease. In normal maintenance, the gentle application of a piece of canvas to the commutator and slip rings occasionally should keep them in good condition. A shiny, coffee-colored surface, which is clean and without grooves or scratches, is an indication of a commutator in good condition. In smoothing commutators or slip rings, crocus cloth or fine sandpaper No. 00 or finer, should be used. *Emery cloth must never be applied to electrical machinery.* The ball bearings should be lubricated about every six months. In greasing the machines, remove the drain plugs on the under side of each bearing. Use only a sodium base grease of light consistency. (A tube of grease is furnished with each machine.) Do not use an excessive amount of grease. After greasing, run the machine for a little while to remove all pressure on the bearings before replacing the drain plugs. Great care should be taken to keep the grease and bearings clean. Dirt will destroy ball bearings quickly. The bearings should be washed in kerosene, gasoline, or carbon tetrachloride (pyrene), and replaced at least once a year. Do not permit grease to reach the brushes, brush holders, commutators, or slip rings. Be sure, by occasional inspection, that the brushes are free in the brush holders, removing them and cleaning the sides of the brushes occasionally to prevent binding.

The interior of the transmitter should be kept clean and free from dust. Accumulations of dust and moisture over a long period may cause serious breakdowns.

The keying relay which is located on a bracket at the right side of the transmitter normally should need no attention over a period of time. The contacts may occasionally be cleaned by rubbing with a piece of crocus cloth or fine sandpaper. Care should be taken to prevent bending the contact springs of the relay when cleaning it. The protective relay located on the same bracket may need to have its contact cleaned with a piece of crocus cloth occasionally in order to insure that the keying circuit of which these contacts form a part is complete. The contacts of the emergency time delay relay on the transmitter base should be sanded about twice a year. The starting relays in the terminal box of motor generator 120A need no attention unless sticking of the contacts is experienced, in which case it will be necessary to sand them.

If at any time the sections of the frequency switch should become sticky in operation, a very slight film of light grease or vaseline may be applied with the finger tips to the switch contacts. In no case should any quantity of grease be allowed on the switch, as this could cause short circuiting from contact to contact and erratic performance of the oscillator.

In case of failure of the snap type switches on the transmitter panel, they may be removed from the back. This is accomplished by unscrewing the knobs of all three switches, removing the designation strip and unscrewing the two screws which hold the switch in question. The wires connecting to the switches are so formed that they may be removed without tagging and placed on a new switch without question, as the leads are retained in position even though disconnected.

13–1c. Mackay Radio Transmitter 167AY (Component of FT–106 Marine Radio Unit)—Radio transmitter 167AY is designed to provide radiotelegraphic transmission of any frequency between 2 and 24 mc. The transmitter will deliver over 200 watts cw on all frequencies between 2 and 16 mc and over 150 watts between 16 and 24 mc. A special cascaded plate supply circuit in this transmitter provides radio frequency excitation of the final stage proportional to the antenna load imposed on the amplifier plate circuit. The antenna coupling circuit has been specially designed to insure satisfactory operation on any antenna which may be encountered aboard ship. Meters have been placed in the transmitter circuits to determine all necessary operating conditions.

1. *Frequency Stability.* The maximum frequency deviation from any preset value will in no case exceed ± 0.05 percent due to all causes. Under normal conditions of operation, even greater frequency stability can be expected of the 167AY transmitter.

2. *Power Supply.* All power for operation of the 167AY high-frequency transmitter is obtained from the main motor generator of the Marine Radio Unit and the rectifier circuits of the 155AY transmitter. An IF-HF switch mounted on the panel of the 155AY transmitter controls the transfer of power to the 167AY transmitter. This switch is a three-pole double-throw switch, the first pole of which completes the circuit to the filament transformer of the 167AY transmitter. The second pole of the IF-HF switch transfers the high-voltage d-c output of the full-wave mercury-vapor rectifier to the plate circuit of the 167AY transmitter, simultaneously opening the circuit to the plates of the 155AY transmitter. The third pole of the IF-HF switch opens the filament circuit of the power amplifier tubes in the 155AY transmitter whenever the switch is in the HF position, thereby reducing the load on the 120-cycle winding of the motor generator. An adjustable compensating resistor in the primary of the filament circuit of the 155AY transmitter controlled by one pole of the IF-HF switch compensates for this loss of load on the 155AY filament transformer and maintains the voltage constant as the switch is changed from one position to another. The method of adjusting this variable compensating resistor is described in the paragraph entitled "Adjustment of Transmitter."

3. *Method of Signaling.* The 167AY transmitter is keyed by the keying relay of the 155AY transmitter, one set of contacts of which keys the primary of the rectifier, and a second set which keys the plate supply of the oscillator of the 167AY.

Since the oscillator and the buffer stages of the 167AY transmitter are dependent on the 115-volt d-c line voltage for plate supply, it is impossible to operate the 167AY transmitter except with the main motor generator.

4. *Type of Circuit.* The radio-frequency circuits of the 167AY transmitter shown in Figure 13–4 include an oscillator, a buffer stage, three multiplier stages, and a power amplifier stage. The oscillator stage employs a type 76 tube which may be used as either a crystal oscillator or a master oscillator. As a master oscillator, this stage forms a tuned-plate, untuned-grid inductive feedback type of oscillator. As a crystal oscillator, this forms a tuned-plate, untuned-grid inductive feedback oscillator with the crystal inserted paralleling the grid inductance. This will oscillate whether or not a crystal is inserted in the crystal jack. It is therefore recommended that a shorting plug be inserted in those jacks in which no crystal is used, thus preventing transmission on frequencies other than those desired.

The buffer stage consists of a 6L6 tube used as an untuned-grid, untuned-plate amplifier. This stage is also dependent on the line voltage for plate supply but is not keyed as is the oscillator.

Three frequency-multiplying stages are employed to increase the oscillator frequency 2 to 12 times, resulting in output frequencies of 2 to 24 mc. Arrangement of the multiplier stage is as follows:

Oscillator Frequency Range	*Multiplier No. 1 Frequency Range*	*Multiplier No. 2 Frequency Range*	*Multiplier No. 3 Frequency Range*
1–2 mc	2–4 mc	4–8 mc	8–16 mc 12–24 mc

A frequency-multiplier switch labeled MULT SELECTOR, selects the number of multipliers required to produce the desired output frequency, disabling the unused multipliers by removing their plate and screen voltages. If, for instance, the desired output frequency is in the 8 to 16 mc range, the multiplier selector switch is placed in position 3, and all three multiplier stages are tuned, as described below. All three multiplier dials will be placed at similar readings. All three multipliers employ 6L6 tubes in a tuned-plate circuit. The first two stages are straight doublers, while the third stage functions as a doubler or tripler to obtain frequency multiplication of 8 or 12, as the case may be. The third multiplier stage incorporates a single tuning condenser and a coil in which the necessary taps have been taken off to permit either doubling or tripling, the required combination being switched into the circuit by placing the MULT SELECTOR switch in position 3 or 4. A milliammeter with a selector switch is used to read the plate and screen current of each frequency multiplier stage as it is tuned.

Two beam power tubes in parallel are used in the power amplifier stage. The grids of these tubes are connected by means of the multiplier selector switch to the output of whichever frequency multiplier is required to produce the desired frequency. It is possible to double the frequency in the power amplifier. However, since the output and efficiency are very low when this is done, it is recommended that the frequency supplied to the grid of the 813's be the same as the output frequency of the transmitter.

The plate circuit of the power amplifier tube consists of a tapped inductance, portions of which are selected by the amplifier range switch, a tuning condenser AMP TUNING, and a coupling condenser labelled ANT COUPLING. The inductance is divided into two sections, with several heavy turns to provide for the high currents associated with operation between 16 to 24 mc. The selector switch is so designed that extra heavy contacts and short paths are provided for these frequencies. The coupling condenser is a high-capacitance unit, placed in the ground leg of the tank circuit across which is developed a voltage required to feed the antenna. The antenna tuning circuit is isolated from d-c by the blocking condenser C34. The antenna circuit is arranged for resonance at all frequencies. This is

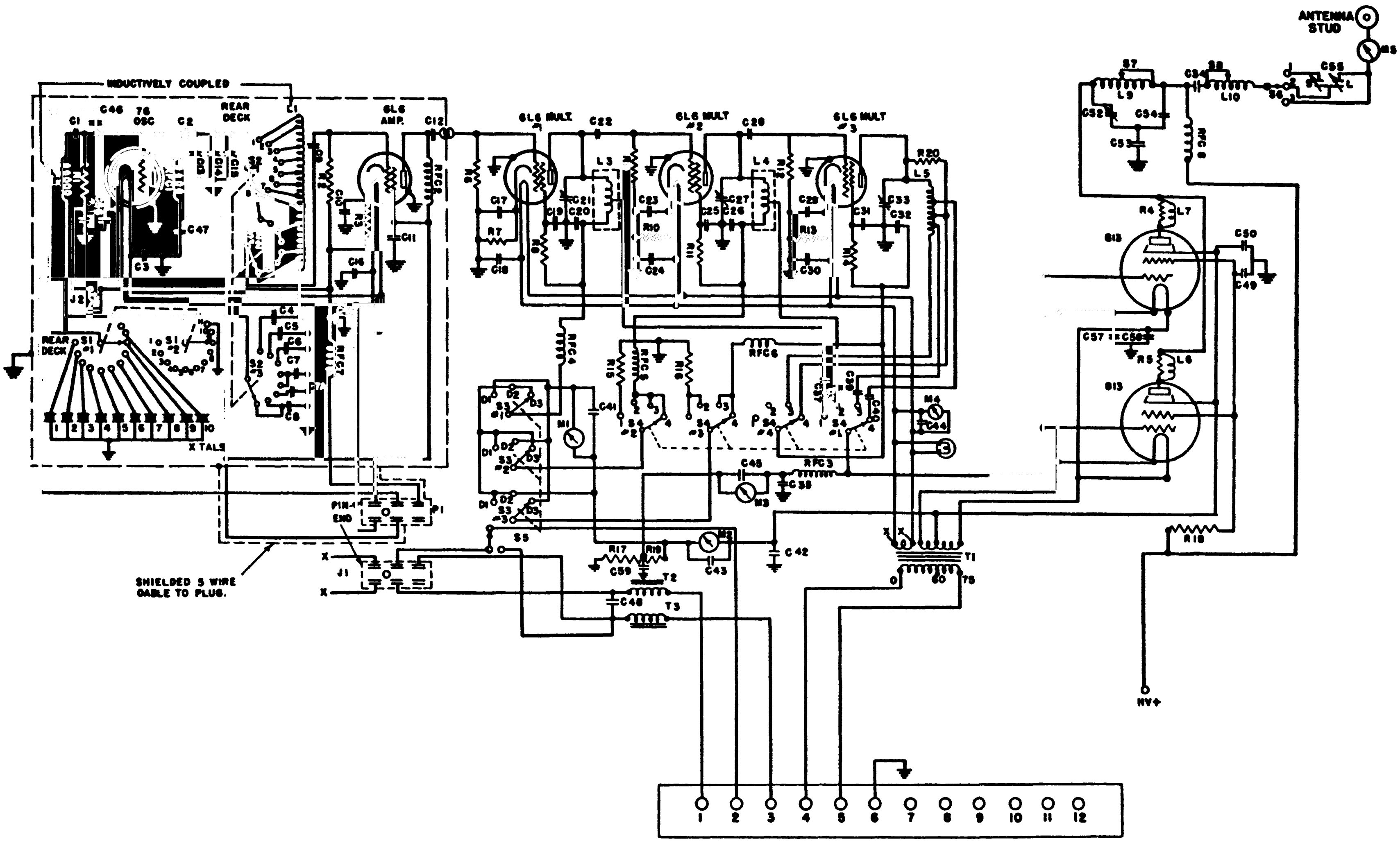


FIG. 13–4. Schematic circuit diagram of the 167AY high frequency radio transmitter, a component of the Mackay FT-106 marine radio unit.

made possible by the use of a tapped loading coil and a two-unit condenser. A three position switch, labeled ANT SWITCH, serves to determine which combination of circuit elements is used to tune the antenna. In the number 1 position, the two condenser sections are placed in series. In the number 2 position, only a single section of the condenser is used; and in the number 3 position, the condenser is completely out of the circuit. The six-position switch, labeled ANT INDUCTANCE, shorts out whatever portion of the antenna tuning coil may not be needed.

The power amplifier stage is equipped with a grid meter and a cathode meter to enable adjustments to be made to the proper values of loading.

The d-c plate current flows through the power amplifier and multiplier tubes in cascade, that is, the current first flows through the power amplifier tubes and then through the multiplier tubes in a regulating resistor. The voltage supplied to the plates and screens of the multiplier tubes is thereby controlled by the current flowing in the power amplifier stage. The grid circuit of the power amplifier is returned to a point on the regulating resistor which is negative with respect to the cathodes of the power amplifier tubes. This voltage is also controlled by the plate current of the power amplifier tubes and protects them by biasing the amplifier tubes and maintaining the amplifier cathode current at a safe value should the grid drive be removed. The plate and screen current of the power amplifier tubes are held at a low value until the multiplier stages are adjusted. As soon as voltage is supplied to the grids of the power amplifier tubes, the current flowing in the power amplifier and multiplier tubes is simultaneously increased. This circuit also provides against high radio-frequency voltages in the power amplifier plate circuit which would otherwise occur should the antenna circuit be detuned or opened, as the decreasing plate current in the power amplifier plate circuit when loading is removed results in an immediate decrease in grid drive, and the current flowing in the driver stages as well as the power amplifier stage is reduced to a low value.

5. *Metering Facilities.* Five meters are mounted on the panel of the 167AY transmitter to read all the necessary currents and voltages to determine proper operation of the transmitter. The left-hand meter, labeled MULT PLATE, indicates the current drawn by the plate and screen grid of the multiplier stages. This meter may be switched to read this current at any one of the three multiplier stages by means of the switch located centrally on the panel, labeled PLATE CURRENT. The second meter designated AMP GRID reads the combined grid current of the two power amplifier tubes. The center meter, labeled AMP PLATE, reads the combined cathode currents of the power amplifier tubes. The fourth meter, labeled FIL VOLTAGE, is inserted in the filament circuit of the multiplier and oscillator stages. It serves to indicate whether the filament voltage is proper. The right-hand meter on the panel, labeled ANT CURRENT, indicates the current flowing in the output stud of the transmitter. Although this current may be small or large, depending on the frequency and the antenna used, a maximum reading will always indicate maximum power supplied to the antenna.

6. *Transmitter Construction.* Radio transmitter 167AY consists of a hinged front panel on which are mounted shelves and sub-assemblies containing the switches and components of the transmitter. The front panel is hinged at the bottom and the components are so located that the panel will swing forward with little effort. It is held in position with captivated thumbscrews, and a handle is provided to permit easy opening. Stops are provided to hold the transmitter panel in position when it has been lowered 90°. All leads from the transmitter are brought out with extra flexible hinge wire to a terminal board mounted in the case of the unit adjacent to the center section. The antenna output circuit is brought to a clip mounted on an insulator near the top of the panel, at which point it engages with a stud, when the transmitter is in the closed position. The high voltage lead to the transmitter runs in the main hinge cable but does not connect to the terminal board on the unit, but runs instead to a fuse box mounted on the rear panel, in a closed metal box, preventing accidental contact with this high voltage. The oscillator and buffer stages are constructed in a small shock mounted compartment located on the lower right corner of the front panel. This compartment is entirely removable by detaching the power cable plug and radio frequency feeder and removing the knobs and nuts on the shock mounting cushions.

To the left of the oscillator compartment is mounted the multiplier shelf. On this shelf are the multiplier tubes, coils and condensers, and the selector switch associated with the multipliers. The frequency check switch located with the controls in the multiplier shelf is mounted directly on the front panel, and next to components mounted on the multiplier shelf. The multiplier shelf is mounted rigidly to the front panel and is supported in the rear by a bracket from the shelf across the bottom rear of the transmitter. This shelf contains the filament transformer and the filter components, and is supported by the brackets of the transmitter frame and supports in turn the multiplier shelf, as well as the components mounted on the shelf.

Above the oscillator compartment and the multiplier shelf is the amplifier shelf. This contains the power amplifier tubes, power amplifier plate circuit, and the antenna tuning components. These components are so arranged that easy access is obtained to any component, should it be necessary to check it or to make repairs.

All shelves, brackets, and panels are copper plated to prevent radio frequency losses to the adjacent radio-frequency components. Additional shielding is provided for the 1st and 2nd multiplier plate coils by aluminum shield cans which are fastened to the multiplier shelf by machine screws tapped into the shelf.

The filament rheostat used in connection with the 167AY transmitter is mounted to the left of the receiver, below the transmitter.

7. *Adjustment of Transmitter.* Prior to operating the transmitter, the filament transformer must be connected to the proper tap and the compensating resistor in the filament circuit of the 155AY transmitter should be adjusted for the line voltage prevalent on the vessel. These adjustments are made in the following manner: When the ship's d-c line voltage is between 90–110, the filament transformer should be connected on taps 0 and 60. For voltages between 110 and 120 volts, the filament transformer should be connected on taps 0 and 73.

The filament compensating resistor of the 155AY transmitter can best be set by trial and error adjustment. In general, a larger amount of resistance will be required in this resistor when the line voltage is high. The exact setting will depend on the line voltage and on the tubes used and will, in general, need to be readjusted when either the line voltage or the tube complement is changed. A preliminary adjustment of this resistor should be made at approximately 5 ohms, that is, with nearly the full resistor in the circuit. The main motor generator may then be started with the IF-HF switch in the IF position. With this done, the filament voltage of the 155AY may be adjusted to 6.3 volts as indicated on the voltmeter. The IF-HF switch is now turned to the HF position and the filament voltage of the 155AY is again read. If the voltage has raised, additional resistance should be inserted in the compensating resistor, and if the voltage has dropped, the resistance of the compensating resistor should be reduced. In making the above test, the filament rheostat of the 167AY transmitter should be adjusted, of course, to provide 6.3 volts as indicated on the filament voltmeter of that transmitter. Since the final amplifier tubes of the 155AY will draw a heavy current when first lighted, it is recommended that the comparison be made each time an adjustment is tried by switching from the IF to the HF position, thereby avoiding the heavy surge and the corresponding drop in filament voltage of the 155AY, due to starting the cold tubes. If the line voltage of the ship is reasonably constant, it may be unnecessary to readjust either filament rheostat at any time, when the IF-HF switch is transferred from one position to the other.

The three oscillator controls are located at the lower part of the front panel. The control at the left, labeled OSC RANGE, permits the selection of the oscillator band for the desired frequency. There are eight oscillator bands tuned by the oscillator tuning dial, covering a fundamental frequency band of 1 to 2 mc. The right-hand switch, marked CRYSTAL SEL., provides for the selection of any crystal supplied with the transmitter or permits the use of the oscillator as a self-excited device. In the latter case, the crystal selector switch is placed in the E position. Each of the oscillator bands is separately calibrated and curve sheets for all bands are provided.

To adjust the transmiter to any frequency, divide the output frequency by 2, 4, 8, or 12, whichever divisor results in a frequency between 1 and 2 mc. Or, refer to the table below to determine in which output frequency range the desired frequency falls, and divide by the multiplier indicated under the column headed *Multiplier Selector.* The multiplier selector switch is always placed in the position corresponding to the last multiplier used.

Output Frequency (mc)	*Multiplier No 3 (mc)*	*Multiplier No 2 (mc)*	*Multiplier No 1 (mc)*	*Multiplier Selector*	*Oscillator Frequency (mc)*
2– 4			2–4	1 (X2)	1–2
4– 8		4-8	2-4	2 (X4)	1–2
8–16	8–16	4-8	2–4	3 (X8)	1–2
16–24	16–24	4–8	2–4	4 (X12)	1–2

From the calibration data determine the oscillator range and dial setting corresponding to the fundamental frequency in the 1 to 2 mc band. If the self-excited oscillator is to be used, set the crystal selector in position E. Set the oscillator range switch on the current band number and the oscillator tuning dial at the proper point as determined by the curves.

If a crystal is to be used, the crystal selector switch may be placed in any crystal position and the crystal inserted in the corresponding holder. When a crystal is used, tune the oscillator dial to 3 or 4 main divisions lower than the corresponding electron oscillator setting. For instance, if the curves call for an oscillator dial reading 12.50, set the dial at 8.50 to 9.50 when a crystal is used. The crystal will be, of course, ground for the frequency corresponding to 12.50 on the curve.

After the transmitter has been properly adjusted for any frequency at which frequent operation is expected, all readings should be recorded on the cards provided on the front panel for this purpose. The adjustment of the power amplifier and antenna coupling transformers will depend, of course, on which antenna is used for the 167AY transmitter.

Each setting of the oscillator will provide four output frequencies. As is to be expected, all four of these frequencies will not fall in bands assigned for marine use. In selecting an oscillator frequency, either for use of the self-excited oscillator, or to determine the frequency of a crystal, the output frequency is divided by 2, 4, 8, or 12, whichever divisor provides a frequency in the 1 to 2 mc band. This frequency is set up on the oscillator, either with the self-excited oscillator or using a crystal of the correct frequency.

A frequency chart (p. 526) indicates the crystal or self-excited oscillator frequencies which must be selected to provide marine frequencies. The figures in light print are output frequencies which may not be used commercially because they are not an assigned band. The heavy figures are working and calling frequencies which are usable for commercial purposes, the calling frequencies being preceded by the letter C. It is evident that proper choice of crystal or self-excited oscillator frequencies will permit operation on a number of bands. This chart may be used in setting up the self-excited oscillator to marine assignment or in determining the frequencies of crystal. It is not the intention to indicate that the transmitter is restricted to the frequencies outlined, as operation may be conducted at any point in the entire band of 2 to 24 mc, in accordance with the attached calibration curves, providing the station is licensed for operation on the frequency used.

In adjusting the self-excited oscillator to the calibration curves, it should be remembered that the ability of the oscillator to be reset is much greater than can be realized by reference to the calibration curves. On the curve sheets, there are but 10 divisions between each main division and each of the 10 divisions represents 10 dial divisions. Since it is obviously impossible to estimate much closer than ½ of one division on the calibration charts, which is equivalent to 5 dial divisions, the curve should

FREQUENCY CHART FOR MACKAY 167AY RADIO TRANSMITTER

No.	Self-Excited or Crystal Freq.	Multiplier No. 1 (Sel. Sw. Pos. 1)		Multiplier No. 2 (Sel. Sw. Pos. 2)		Multiplier No. 3	
		Osc. X2		Osc. X4		Sw. Pos. 3 Osc. X8	Sw. Pos. 4 Osc. X12
1	**1845**	3690		7380		14760	**22140**
2	**1843.75**	3687.5		7375		14750	**22125**
3	**1843.33**	3686.66		7373.33		14746.66	**22120**
4	**1842.5**	3685		7370		14740	**22110**
5	**1841.66**	3683.33		7366.66		14733.33	**22100**
6	**1840**	3680		7360		14720	**C22080**
7	**1839.58**	3679.16		7358.33		14718.66	**22075**
8	**1838.33**	3676.66		7353.33		14706.66	**22060**
9	**1837.5**	3675		7350		14700	**22050**
10	**1836.66**	3673.33		7346.66		14683.33	**22040**
11	**1835.41**	3670.83		7341.66		14633.33	**22025**
12	**1560**	3120		**6240**		**12480**	18720
13	**1557.5**	3115		**6230**		**12460**	18690
14	**1556.25**	3112.5		6225		**12450**	18675
15	**1555**	3110		**6220**		**12440**	18660
16	**1552.5**	3105		**C6210**		**C12420**	18630
17	**1548.75**	3097.5		6195		**12390**	18585
18	**1546.87**	3093.75		6187.5		**12375**	18562.5
19	**1545**	3090		6180		**12360**	18540
20	**1388.33**	2776.66		5553.33			**16660**
21	**1386.66**	2773.33		5546.66			**16640**
22	**1383.75**	2767.5		**5535**		**11070**	**16605**
23	**1383.33**	2766.66		5533.33			**16600**
24	**1382.5**	2765		**5530**		**11060**	**16590**
25	**1381.87**	2763.75		**5527.5**		**11055**	16582.5
26	**1381.25**	2762.5		**5525**		**11050**	**16575**
27	**1380**	2760		**C5520**		**C11040**	**C16560**
28	**1378.75**	2757.5		**5515**		**11030**	16545
29	**1378.12**	2756.25		**5512.5**		**11025**	16537.5
30	**1377.5**	2755		**5510**		**11020**	**16530**
31	**1376.66**	2753.33		5506.66			**16520**
32	**1375**	2750		5500			**16500**
33	**1373.33**	2746.66		5493.33			**16480**
			Osc. X3		Osc. X6		
34	**1041.25**	2082.5	3123.75	**4165**	6247.5	**8330**	
35	**1040**	2080	3120	**4160**	**6240**	**8320**	
36	**1037.5**	2075	3112.5	**4150**	6225	**8300**	
37	**1035**	2070	3105	**C4140**	**C6210**	**C 8280**	
38	**1032.5**	2065	3097.5	4130	6195	**8260**	
39	**1031.25**	2062.5	3093.75	4125	6187.5	**8250**	
40	**1030**	2060	3090	4120	6180	**8240**	

Note: "C" denotes calling frequencies.

be used only as a guide in calibrating the transmitter. An accurate heterodyne frequency meter should be employed for adjusting the oscillator precisely to frequency. The curves are calibrated sufficiently close to place a transmitter well within the required tolerance. It may be used for actual calibration when more accurate means of frequency adjustment is unobtainable. In such case, the fractional part of a division on a curve sheet must be estimated in tenths of a division and the oscillator dial set accordingly.

It has been mentioned heretofore that the oscillator dial is adjusted to about 3 or 4 main divisions lower frequency in numbers for a crystal than the corresponding setting for self-excited oscillator as indicated on the curves. In initial adjustment of a crystal frequency, the high voltage fuse should be removed, and a one milliampere meter plugged into the jack in the oscillator unit. With the key depressed and no crystal in use, the meter will read .1 ma or less. When a crystal is switched into the circuit and the dial adjusted lower in frequency than the corresponding self-excited oscillator setting, the meter will increase in reading to about .13 ma. Adjustment of about .2 to .3 is suitable. Tuning of the oscillator permits adjustment of the crystal frequency within a restricted range. The crystal should always be checked when first installed with a heterodyne frequency monitor, and the oscillator dial adjusted to precise frequency as indicated by the beat note, but always lower on the oscillator dial than the corresponding self-excited oscillator setting.

The self-excited oscillator may be checked for normal operation by observing the oscillator grid current with an external meter as explained above. The grid current used in the self-excited oscillator varies from 0.3 ma on range 8 to 0.1 ma on range 1.

The circuit is one in which oscillation is maintained with the crystal removed. With a crystal in use on any oscillator range, the grid current should continue to read 0.1 ma or less when the crystal is removed. This is essential to correct operation and should be carefully checked at initial setup. Listen to the beat note of the transmitter output with a heterodyne monitor or receiver and tap on the oscillator unit or front panel in the locality of the oscillator. If the self-excited oscillator is used, a microphonic vibration of the tubes will be heard in the earphones. When crystal control is used, and the crystal is properly controlling the oscillator, no sound will be heard and the oscillator frequency will be unaffected by any but the oscillator tuning adjustments.

8. *Operating Instructions.* When the adjustments have been made as outlined in Paragraph 7, the 167AY transmitter is ready for operation. The following procedure should be used. Turn the POWER switch of the 155AY transmitter to MAIN and the IF-HF switch to HF. Start the main motor generator by closing the main line switch located in the base of the right hand section of the Marine Radio Unit and turning the LINE switch on the 155AY transmitter to ON. When the motor generator has come up to speed, adjust the filament voltage of both transmitters to 6.3 volts. The oscillator may be tuned following the instructions given in Paragraph 7 above, and the multipliers and power amplifier antenna coupling circuits may be tuned approximately, using the curves supplied. The field rheostat on the 155AY transmitter should be turned to the full counterclockwise position and the key may then be closed. Check the tuning of each of the multipliers by checking for plate dip. Tuning the multiplier which results in the proper output frequency, that is, the multiplier which is connected to the power amplifier grids will result in a reading on the amplifier grid current meter and a simultaneous rise in the amplifier plate current. After amplifier grid current is indicated, quickly check the tuning of each multiplier in use to insure that a maximum amplifier grid current is being obtained.

In tuning the multipliers, it will be possible to obtain dips at several points on the dial. It will, therefore, be necessary to tune to the proper dip. This can best be assured by tuning the multipliers first using the tuning curves, and then tuning with the power on. A rough check of the choice of the proper dip may be made by comparing the desired frequency of operation of a multiplier with the band which that multiplier covers. Low readings on the multiplier dial correspond to the lower portion of the band which the multiplier covers.

In adjusting the power amplifier, the antenna coupling condenser should first be set at zero. Reference to the plate tuning chart will indicate which tap on the amplifier range switch should be used for any output frequency. Having set this switch, hold down the key and rotate the amplifier tuning dial until the amplifier plate current meter drops to 100 ma or less. The setting of this plate condenser should be approximately as shown on the sheet. In adjusting the plate circuit to resonance, it will be noted that the readings of all three meters are reduced to low values.

9. *Antenna Tuning Procedure No. 1.* The antenna switch should be in position 1 for frequencies from approximately 8 to 24 mc and in position 2 for frequencies from 2 to 8 mc, although this will depend largely upon the antenna and can best be determined by trial. Place the antenna tuning dial at 50 and, with the key depressed, rotate the antenna inductance switch until a tap is reached which causes the amplifier plate current to rise. Now adjust the antenna tuning dial until the maximum indication is shown on the antenna ammeter. Slowly increase power by turning the field rheostat on the 155AY clockwise. If, when the rheostat is all the way to the right, the amplifier plate current meter reads less than 380 ma, increase the reading of the antenna

coupling dial. As this dial is increased numerically, the amplifier plate current meter reading will increase. During this adjustment, keep the amplifier tuning dial always at the point where minimum amplifier plate current is indicated. No difficulty should be obtained in securing an adjustment of the tuning and coupling condensers which will provide full loading of the amplifier tubes. Do not exceed 380 ma under any circumstances.

With the coupling condenser on zero, minimum coupling is obtained. If an unusual antenna condition causes the amplifier plate current to read an excessive value, with the antenna coupling condenser at zero, detune the antenna tuning condenser somewhat, or reduce the power by means of the field rheostat. In any case, always determine that the amplifier tuning condenser is adjusted for minimum amplifier plate current under any condition of loading.

The setting of the coupling condenser will be higher numerically for the high frequencies. For frequencies up to 16 mc, it will probably never be set higher than 75, but at 24 mc, it may be adjusted close to 100.

10. *Antenna Tuning Procedure No. 2.* When the characteristics of the antenna are such that power is not delivered to the antenna when the above tuning procedure is followed, Antenna Tuning Procedure No. 2 should be followed.

Turn the antenna switch to position 3 and the antenna inductance switch to position 6. The antenna tuning condenser may be left in any position since it is not in the circuit.

With the antenna coupling condenser set at zero and the field rheostat rotated to its full counterclockwise position, close the key and rotate the amplifier tuning condenser until resonance is indicated by a sharp dip in the amplifier plate current meter. When resonance has been obtained, increase the antenna coupling by rotating the antenna coupling condenser in a clockwise direction. Each time the coupling is increased, the power amplifier tank circuit must be reresonated by rotating the amplifier tuning condenser in a counterclockwise direction. It is a simple matter to perform these operations simultaneously by rotating the coupling condenser clockwise with the left hand, while rotating the amplifier tuning condenser counterclockwise with the right hand. When the coupling has been increased to a point where the minimum plate current is approximately 150 ma at resonance of the power amplifier tank, rotate the field rheostat to increase the plate voltage. As the plate voltage is increased, the plate current will increase. If, when the field rheostat is in the full clockwise position, the power amplifier plate current is less than 380 ma, the coupling should be increased and the amplifier tank simultaneously reresonated until the minimum plate current is 380 ma. If the plate current reaches 380 ma before the field rheostat is in the full counterclockwise position, the coupling must be decreased and the amplifier tank reresonated. The amplifier plate current should never be permitted to exceed 380 ma.

At a given frequency, an antenna may have a very high impedance characteristic which would cause excessively high voltages to be developed across the antenna coupling condenser. In this case, the effective length of the antenna should be changed by setting the antenna inductance switch at a position other than position 6.

The indication of the antenna ammeter may be high or low, depending upon the antenna characteristic at the frequency in use. But, in any case, the maximum reading of this meter will represent optimum output.

After the transmitter has been adjusted for any frequency, all readings should be recorded on the cards supplied for this purpose, if it is contemplated to return to this frequency often.

11. *Frequency Checking.* A frequency checking switch has been incorporated in the 167AY transmitter to permit calibration of the oscillator when no heterodyne frequency meter is available for that purpose. Such a calibration should be made whenever the oscillator tuning dial has been removed for any reason or if the operator has reason to believe that the calibration is not correct. This procedure is, of course, an emergency measure and should be used only when an accurate heterodyne frequency meter is not available.

To permit checking frequency, a frequency check switch on the front panel of the 167AY transmitter, when turned to the ON position, permits operation of the oscillator and buffer stages without the use of the power amplifier stage or multiplier stages. With the frequency check switch in the ON position, the transmitter is started in the usual way, that is, turning the IF-HF switch to the HF position and starting the main motor generator of the 155AY transmitter. The key must not be pressed, since this will result in the transmission of a signal.

The receiver immediately below the 167AY transmitter is now tuned to a station in the 2 to 4 mc range, whose frequency is accurately known. The oscillator of the 167AY transmitter is now tuned to approximately ½ the frequency of the station against which calibration is being made. By tuning the 167AY transmitter until a zero beat is heard in the receiver, the oscillator of the transmitter has been tuned to exactly ½ of the frequency of the known shore station. By repeating this procedure against a number of fixed frequency shore stations, it is possible to obtain enough points to redraw the calibration curve for the oscillator of the transmitter.

The frequency check switch should normally be left in the OFF position. No harm can result from operation of the transmitter with this switch in the ON position. However, if break-in operation is contemplated, interference from the oscillator of the transmitter will result, unless this switch is in the OFF position.

12. *Maintenance.* The interior of the transmitter should be kept clean and free from dust. Accumulations of dust and moisture over a long period may cause a serious breakdown.

13–1d. Mackay Auto Alarm 101B (Component of FT–106 Marine Radio Unit)—The auto alarm is a device authorized by the International Convention for the Safety of Life at Sea and by other laws, which are intended to increase safety of life and property at sea. Intelligent maintenance of this equipment and careful observation of its operation will assist in furthering the purpose for which it is designed and installed.

The auto alarm, 101B, is a receiving device which will respond to the International Alarm Signal sent by a ship in distress and will call the radio operators on ships receiving the signal to their respective radio rooms as well as notify the deck officers on duty at the time. The International Alarm Signal consists of twelve four-second dashes spaced one second between dashes and is sent on the International distress frequency of 500 kc (600 meters). The auto alarm is chiefly intended for operation on ships carrying only one radio operator but it may be installed on any vessel to guard the distress frequency during such times as the operator on watch may not be listening on that frequency.

The auto alarm system consists of receiving and selecting apparatus located in the radio room, alarm bells and warning lights located on the bridge and in the radio room, and a third alarm bell located in the radio operator's cabin. The auto alarm is placed in service by the radio operator during such times as he is not on watch and the vessel is under way. The alarm bells are intended to call the operator to the radio room when an alarm signal is received or when the auto alarm apparatus refuses to function properly.

Upon receipt of an alarm signal, the auto alarm will cause the bells to ring. On the sounding of such an alarm, steps should be taken to inform the operator immediately so as to guard against the possibility that he may not have heard the alarm. The ringing of the bells also serves to indicate when the auto alarm receiving equipment becomes inoperative due to a failure of power or to the burning out of a tube. Regardless of the reason for sounding the alarm, it can only be stopped from the radio room.

The warning lights located on the bridge and on the Marine Radio Unit, when lighted continuously, with the alarm bells not ringing, will indicate that the auto alarm device is inoperative for reasons outside the instrument itself, such as during heavy electrical storms when static has the characteristics of continuous signals, and during periods when other types of uninterrupted electrical noises may be prevalent. These lights also indicate when the ship's power to the radio room fails during the periods that the auto alarm equipment is in operation. At other times during normal operation of the equipment, these lights may flash at intervals. These intermittent flashes will not indicate that the equipment is inoperative and should be disregarded. When the warning lights remain lighted continuously for a period of five minutes, the radio operator should be informed.

Detailed instructions for the operation and maintenance of the apparatus are given on the pages following. Strict adherence to them will assist in creating the highest degree of safety possible with such an instrument and under circumstances most satisfactory to all concerned. It should be realized that the auto alarm is an electrical and mechanical device and as such, it must be given intelligent supervision and careful maintenance to insure satisfactory operation.

These instructions are not intended to supplant those instructions issued by the Federal Communications Commission or other governmental agencies having jurisdiction over the auto alarm equipment and the details covering its operation. It is recommended that all applicable regulations be carefully studied.

The auto alarm 101B consists of the following units:

101B Equipment

Auto alarm receiver 101B
Auto alarm selector 101B
Antenna switch (part of 107A switch)
Alarm bells (3) (one in Marine Unit)
Warning lights (2) (one in Marine Unit)
Auxiliary equipment consisting of:
  24-volt storage batteries (2 sets)
  Charging equipment for above
  Receiver power supply unit
  Auxiliary 90-volt B battery
Instruction books
Set of spare parts.

The power requirements for the equipment are:

1.4 amp from the 24-volt batteries
12 to 25 ma from the power supply unit or from the 90-volt B battery
1.7 to 2.0 amp from the ship's 115-volt d-c line for the charging of the batteries and for operation of the power supply unit.

1. *Receiver.* It is the function of the receiver to accept all signals within the prescribed frequency band of 487.5 to 512.5 kc, modulated at least 30 percent at frequencies between 100 and 2500 cycles, and transform those signals into such a form that they will operate the signal relay whenever those signals produce at the receiver input terminals an r-f voltage of 500 microvolts or more.

Other requirements placed upon the receiver are that it must function equally well with very strong signals as with weak ones and that it must accept a weak alarm signal in the presence of strong interference. These requirements have been met in the design of the various circuits and components entering into the make-up of the receiver. Although the circuits of the receiver are not very different from those of any other one-stage TRF receiver, they are, however, in many respects different from the usual receiver, in that the parts have been designed for this specific service, that of operating a relay as nearly as possible in conformance to the signals applied to the receiver. Steps have been taken therefore to provide as great an overload capacity as possible, to minimize the tendency toward "blocking," and to make its operation as "fast" as possible in order to utilize any breaks in the signals. In this manner then, the relay "B" will act as a "key" and deliver to the selector impulses which are a faithful reproduction of the signal combinations applied to the input of the receiver.

The receiver of the auto alarm is of the tuned radio-frequency type employing a single stage of radio-frequency amplification in which the tuning is fixed, followed by a detector, two stages of audio-frequency amplification and a rectifier.

The receiver uses five tubes of the 6-volt heater type. They are: one 6D6 as the r-f amplifier, one 75 as a detector, two 76's as audio amplifiers, and an 89 as a rectifier.

Referring to the schematic circuit diagram, Figure 13–5, the heaters of tubes VT1 to VT4 are in series and are then connected in parallel with the heater of tube VT5 and its series resistor. The total heater current passes through the winding of the low resistance relay A which operates and opens the alarm bell circuit through its back contacts 2, at the same time closing its front contacts 1, thereby completing the plate supply circuit to the receiver. This relay is adjusted to operate when full heater current passes through its winding. The burning out of any heater will reduce the current to a value which will release the relay, closing the contacts which complete the alarm bell circuit, thus indicating that the equipment is out of order.

The antenna feeds the first of two resonant circuits through the small coupling condenser C5, a resistor R1 being connected between the antenna and ground to drain off static charges accumulated by the antenna. The two resonant circuits L1–C1 and L2–C2 are each tuned to 500 kc and are over-coupled with each sufficiently to produce two small humps, one on either side of 500 kc. The second circuit feeds to grid of the r-f amplifier tube VT1. This tube is in turn coupled to the detector tube by two similar circuits L3–C3 and L4–C4. In this manner, the receiver is made to respond efficiently to signals within the frequency band of 487.5 kc to 512.5 kc and to exclude signals outside this band in the manner specified by the regulations. The resonant circuits are adjusted to proper resonance before leaving the factory, except for the first, or antenna circuit, which is adjusted at installation. The r-f transformers use air core coils which are tuned by air dielectric condensers in order to maintain proper resonance under various conditions of temperature and humidity.

The detector VT2 employs diode rectification and feeds the audio frequency signals to the rectifier tube VT5 through two audio frequency amplifier tubes VT3 and VT4 which are transformer coupled to T3, T4, and T5. The condensers C8, C9, C10, and C11, together with the broadly resonant circuit L5–R4–C15 are for the purpose of providing a flat frequency characteristic to the audio amplifier over the frequency range of 100 to 2500 cycles per second.

The rectifier tube VT5 operates upon the principle of plate rectification. When a signal voltage is applied to its grid, its plate current increases from its low no-signal value to a higher average value sufficient to operate the signal relay B, which is included in its plate circuit. The value of this plate current is indicated by the milliammeter MA which is mounted on the panel of the receiver unit. The condenser C18 connected between the plate and cathode of the rectifier tube serves to smooth out the current and prevent relay chatter. The contacts 1, of this relay, control the operation of the selector, or timing unit. The condenser C19 and the resistor R11 are connected across the relay contacts to reduce sparking and radio-frequency interference in the receiver.

The sensitivity control R6 is a potentiometer for controlling the screen grid potential of the r-f amplifier tube so that the sensitivity of the receiver may be adjusted between the limits of approximately 250 and 50,000 microvolts. This is made use of in adjusting the sensitivity of the receiver to the "optimum" value for the prevailing conditions of noise or static. This optimum value is the highest sensitivity which can be used without causing the signal relay to be energized except momentarily by the noise or static during periods of no-signal. A higher sensitivity would cause the signal relay to be energized by the noise or static for extended periods during which time it would be incapable of further operation by signals.

A buzzer with its controlling push button SW2 of the nonlocking type is provided for the production of r-f test signals. The output of the buzzer is coupled into the antenna circuit by means of the buzzer antenna which is a short piece of wire from the buzzer to a point near the antenna lead. This antenna is adjusted to produce an r-f input into the receiver of about 2000 microvolts.

The switch SW3, also of the nonlocking type, opens the circuit to the bridge and cabin bells when

depressed so that those bells may be cut out of circuit when desired during routine tests.

The phone jack, J, connects a pair of headphones to the low impedance winding of transformer T5, feeding the rectifier, so that the operation of the receiver may be monitored by ear.

All component parts of the receiver are mounted upon a formed metal chassis which is attached to the hinged door of the metal cabinet. The milliammeter, sensitivity control knob and scale, buzzer push button knob, the bridge and operator's cabin bell disconnect switch knob and the monitoring phone jack are located on the front of the cabinet door. All parts are protected against the effects of temperature and humidity.

The grid, plate and cathode circuits of the receiver are isolated from the grounded chassis and cabinet except through by-pass or grounding condensers so that the receiver may be operated from power supplies which may or may not themselves be grounded.

2. *Selector.* It is the function of the selector to accept and register the correct auto alarm signal and sound the alarm and to reject all other signals and atmospherics. It does so by measuring the length or duration of the signals as well as the spaces between the signals.

The selector of the auto alarm consists of three motor-driven timing elements and a bank of counting relays. The timing elements are cams which operate contacts after a certain angular rotation. The motor, which rotates the cams, operates during all the time the equipment is "Watching." It is shunt wound and is equipped with a governor in which centrifugal force opens contacts and places a resistance in series with the armature circuit, thereby maintaining the speed of the motor constant at 1800 rpm. The motor, through a reduction gear, drives a slow-motion shaft at 6 rpm. On this shaft are two electromagnetic clutches which, when energized, engage and rotate the cams. Two of these cams are integral with each other and are operated by one of the clutches. This clutch measures the length of the dashes. The second clutch operates the third cam and measures the length of the spaces between the dashes. The counting of the dashes is accomplished by a bank of relays connected to form a counting chain.

The motor and timing cam mechanism is mounted upon its own independent base frame which, in turn, is mounted upon the hinged door of the selector cabinet by means of flexible mounting feet so that timing will not be affected through bending or mechanical displacement of the door. The counting relays are also mounted upon an independent base which in turn is fastened to the door.

A "Release Key" of the push button type, on the front panel of the unit, is used to release the alarm bell circuit after it has been set off by the proper sequence of alarm signals. It will not, however, release the alarm if the alarm has been set off through failure of the equipment, and this fact is made use of to differentiate between the receipt of an alarm and the ringing of the alarm bells through failure of the equipment.

The motor has auxiliary contacts of the centrigual type which will operate the alarm bells if the motor speed becomes too slow. Auxiliary overrun contacts are provided in the selector, which are operated by either of the cams should they overrun their normal travel for any reason, thereby stopping the motor and thus preventing damage to the equipment. The centrifugal contacts on the motor will then operate to give the alarm.

A voltmeter, mounted in the front panel, provides a constant check on the 24-volt battery voltage and reads the plate supply voltage when the voltage switch is turned to its non-locking position.

Since the slow-motion shaft of the selector unit revolves at the proper speed, a fourth cam has been mounted upon it to operate a pair of contacts which may be used to key the ship's radio transmitter and thus transmit a correctly timed alarm signal should the vessel be in distress. These contacts are placed in circuit and the motor operated independently of the rest of the auto alarm equipment by means of a switch on the front panel of the selector unit.

All parts entering into the construction of the selector have been treated to protect them from corrosion and the effects of moisture and heat. As in the receiver, the selector circuits are isolated from the chassis and cabinet except through grounding condensers.

The operation of the selector can be best understood by considering an illustrative block diagram, Figure 13-6. This diagram represents a group of devices arranged so that their sequence of operations illustrates the fundamental scheme of the auto alarm selector. In this diagram the unit "Key" represents some form of device which will energize the 3½-second and the 4½-second timer.

The 3½-second timer is a device so arranged that after being energized continuously by the "Key" for a period of 3½-seconds it will operate the "Counter" to record partly a dash, completing the record when the dash stops. This timing device, therefore, will select only those dashes which are 3½ seconds or more in length, and will reject all dashes which are of shorter duration.

The 4½-second timer is a device which starts simultaneously with the 3½-second timer but is arranged so that when energized continuously for 4½ seconds, it will erase any counts which may have been registered in the counter. This timing device, therefore, will act in conjunction with the 3½-second timing device so that the combination of the two devices becomes a dash timer and will select and record only those dashes which are between 3½ and 4½ seconds in length.

The 1½-second timer is a device which is ener-

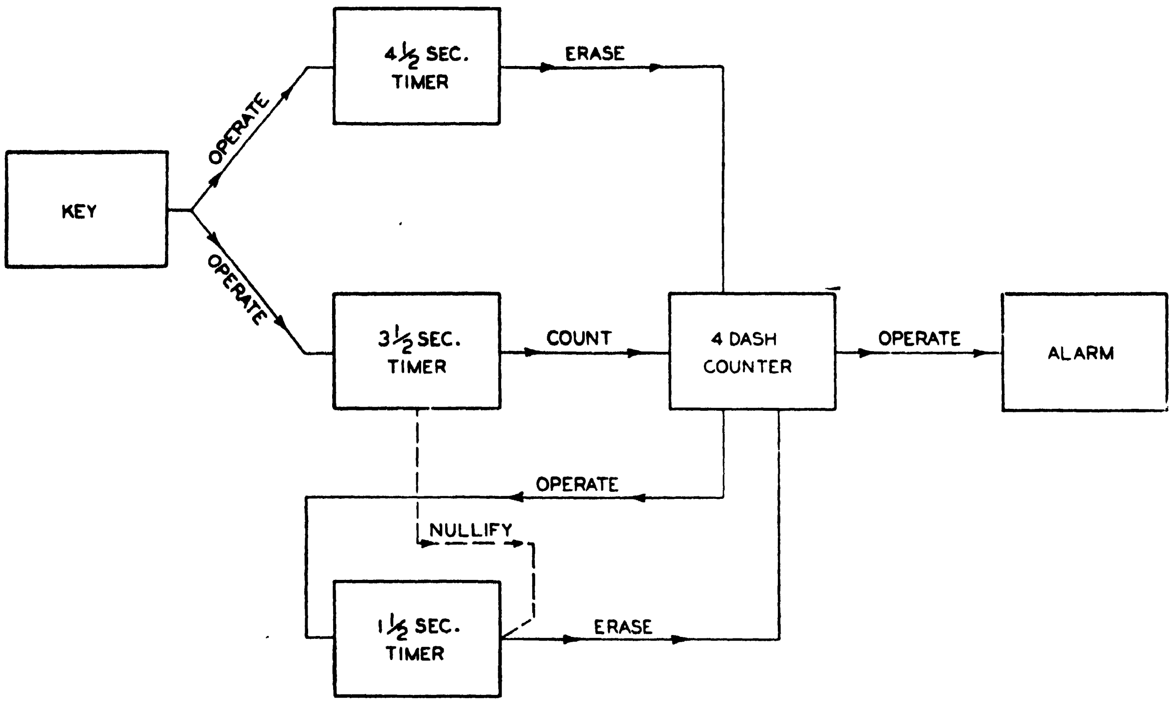


FIG. 13–6. Fundamental block diagram of the Mackay 101B auto alarm.

gized by the counter at the termination of each complete recording of a dash. It is so arranged that after being energized for 1½ seconds, it will erase, normally, all counts registered in the counter. This erasure will return the timer to zero, since it requires a recording in the counter to energize this timer.

This timer is associated with the 3½-second timer in such a manner that this erasing power, which would have become effective after 1½ seconds of operation, is made ineffective, or nullified, during such times that the 3½-second timer is energized. The 1½-second timer, therefore, will continue to operate for the first 3½ seconds of the duration of the succeeding dash, since the previous count remains in the counter.

In this manner we have arranged the 1½-second or space timer so as to measure the space between two dashes and erase the count if the succeeding dash does not begin within the 1½-second interval. Furthermore, the space between the dashes may contain intermittent interference without affecting the count in any way, because during this interval the space timer has no erasing power.

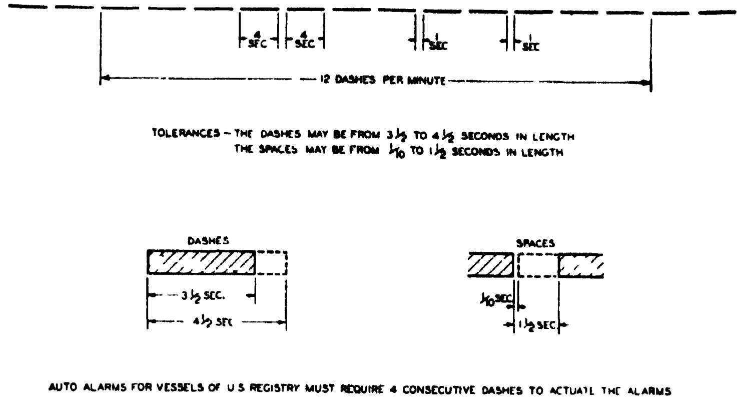
Now, in addition, it is so arranged that when the succeeding dash has existed for 3½ seconds, the partial recording of that dash will release the space timer and reset it to zero. Should this dash be shorter than 3½ seconds, therefore incorrectly timed, the nullifying power of the 3½-second timer stops and the space timer will erase all records.

If the dash is correctly timed, the space timer will have been released after 3½ seconds of the dash, and will be ready to start timing the space between this and the next dash, when the dash ends. If the dash is too long, the counts will be erased by the 4½-second timer.

The "Counter" is a recording device energized by the 3½-second timer, reset to zero by the 4½-second and the 1½-second timers, and arranged to operate the "Alarm" when four complete dashes have been recorded.

This group of units provides an arrangement whereby the counter will only record those operations of the "Key" which conform to the following requirements:

1. The "Key" must be operated continuously for at least 3½ seconds before any count will be recorded by the 3½ second timer.
2. The "Key" must not be operated for more than 4½ seconds or all records will be erased by the 4½ second timer. The correct operation of the key for recording a count is, therefore, from 3½ to 4½ seconds.
3. Each succeeding operation of the key must follow a correct operation within 1½ seconds or all records will be erased by the 1½-second timer.
4. Four successive correct operations of the "Key" are required to cause the "Counter" to actuate alarm.
5. If the "Key" is operated in any other manner than that outlined above, there will be either no counts or such counts as are recorded, less than the total of four, will be erased.


4 SEC
4 SEC
1 SEC
1 SEC
12 DASHES PER MINUTE
TOLERANCES – THE DASHES MAY BE FROM 3½ TO 4½ SECONDS IN LENGTH
THE SPACES MAY BE FROM 1/10 TO 1½ SECONDS IN LENGTH
DASHES
3½ SEC.
4½ SEC
SPACES
1/10 SEC
1½ SEC
AUTO ALARMS FOR VESSELS OF U S REGISTRY MUST REQUIRE 4 CONSECUTIVE DASHES TO ACTUATE THE ALARMS

INTERNATIONAL AUTO ALARM SIGNAL

The auto alarm signal consists of a series of 12 or more dashes sent at the rate of 12 per minute, each dash having a duration of 4 seconds with spaces between the dashes of 1 second duration.

FIG. 13–7. International auto alarm signal.

It will be seen that these requirements placed upon the operation of the key coincide with the form specified for the International Auto Alarm Signal and its tolerances. (See Figure 13–7.)

The above several illustrative units of the block diagram are to be found in the receiver and selector portions of the auto alarm equipment in the following physical form:

> "Key" is relay B in the receiver in conjunction with relay C in the selector.
>
> "3½-second Timer" is the cam marked 3½ in the selector together with its contacts III.
>
> "4½-second Timer" is the cam marked 4½ in the selector together with its contacts II and relay D.
>
> "1½-second Timer" is the cam marked 1½ in the selector together with its contacts IV.
>
> "Counter" is the bank of relays, E, F, G, H, J, K, L, and M, relay M operating the alarm bells.

The operation of the selector will now be described in detail. In tracing the operation, the auto alarm schematic, Figure 13–5, should be consulted.

3. *The First Dash.* By the "first dash" is meant any dash which starts after an interval sufficiently long so that all the equipment is in its normal rest position. At the beginning of this dash, relay B in the receiver is energized by the plate current of the last tube of the receiver. Relay B energizes relay C through the circuit:

> Battery and charger, terminal 18, antenna switch, terminal 19, cam contact I, relay winding C, terminal 14, terminal 12, relay contacts B–1, terminal 11, terminal 15, back contact M2, terminal 16, to charger and battery.

The operation of relay C closes its contacts and the magnetic clutch CL–1 is energized through the circuit:

> Battery and charger to 18 antenna switch, 19, back contacts D–2, contacts C–2, winding CL–1, 16, to charger and battery.

The cams 3½ and 4½ begin to revolve. Cam contacts I open immediately but they have now been bridged by contacts C–1, and relay C remains closed. If the dash does not last for 3½ seconds then its termination opens relay B, breaking the circuit of relay C and thereby opening the circuit of the magnetic clutch CL–1 and the cams 3½ and 4½ return to their zero position. Relay C cannot be energized again until the cam 4½ has reached its zero position and allowed cam contacts I to close.

When a dash has continued for 3½ seconds, cam 3½ operates cam contacts III which operate relay E through the circuit:

> Battery and charger to 18, antenna switch, 19, back contacts D–2, contacts C–3, winding E, back contact F–3, cam contacts III–2, 16 to charger and battery.

The closing of contacts E–1 places the winding of relay E in series with the winding of relay F and both across the battery except that winding F is short-circuited while the cam contacts III–2 are closed.

At the termination of the dash, provided its duration is between 3½ and 4½ seconds, the relays B and C are opened and clutch CL–1 is released, thus opening the cam contacts III–2. Current now flows through relay windings E and F in series through the circuit:

> Battery and charger 18, antenna switch, 19, back contacts D–2, cam contacts IV–I, winding E,

contacts E-1, winding F, back contacts M-2, 16 to charger and battery.

The closing of relay F energizes the magnetic clutch CL-2 through the circuit:

> Battery and charger, 18, antenna switch, 19, contacts F-1, winding CL-2, back cam contacts III-1, 16, to charger and battery.

The closing of relay F also connects relay G into the circuit to receive the next impulse from cam contacts III-2 through contacts F-2 and H-2.

4. *Dash Too Long.* If any dash lasts more than 4½ seconds, cam 4½ operates its cam contacts II and closes the circuit of the winding relay D through the circuit:

> Battery and charger, 18, antenna switch, 19, cam contacts II-1, winding of D, 14, 12, contacts B-1, 11, 15, back contacts M-2, 16, to charger and battery.

Relay D closes and locks up through its contacts D-1 to 19 and battery, by-passing the cam contacts II-1. The back contacts D-2 open the battery supply to the circuits of all counting relays and also clutch CL-1 which returns cams 4½ and 3½ to their zero position. Relay D remains closed as long as the dash continues but opens when the termination of the dash opens relay B. Back contacts D-3 energize the warning lights through the circuit:

> Battery and charger, X, antenna switch, 24, lights, 13, contact D-3, chassis G, 16, to charger and battery.

5. *Space After the First Correct Dash.* The battery side of the circuit of relays E and F has two optional paths one through the cam contacts IV-1 to D-2 and battery, and the other through contacts C-3 to D-2 and battery. One and one-half seconds after the termination of the dash, cam 1½ opens its contacts IV-1. If the next dash has not started, contacts C-3 are also open so that all counting relay circuits including the circuit of relays E and F are broken, thus placing all relays in their rest position. However, if a dash has started, contacts C-3 are closed and relays E and F remain closed. This dash, from the time it started, has caused cams 4½ and 3½ to be operated in the same manner as described for the first dash. If this second dash terminates or is interrupted at some time between the 1½- and 3½-second intervals required for the operation of cam contacts IV and III, respectively, then relays E and F are opened and the first dash is thereby uncounted or erased. It should be noted that the 1½-second interval may be occupied by interference, relay C and cam 4½ and 3½ returning to their zero position at the termination of every dot, dash or static crash without erasing any counts.

6. *The Second Correct Dash.* This dash, having started as described in the previous paragraph and having continued for 3½ seconds, cam contacts III are operated. Came contacts III-2 close relay G as they did relay E for the first dash, while cam contacts III-1 release clutch CL-2. Cam 1½ then returns to rest or zero position, closing its cam contacts IV-1, thereby maintaining a closed circuit for the counting relays E and F even though the dash stops and relay C opens. If this second dash does not last for more than 4½ seconds, it operates counting relays G and H in a similar manner to the operation of relays E and F by the first dash. After the cessation of the second dash, cam contacts III-1 close and start the 1½-second timer whose contacts break the counting relay circuits if the third dash does not start within 1½ seconds.

7. *The Third Correct Dash.* This dash results in the setting up of counting relays J and K through the same sequence as that described for the setting up of relays G and H after the second correct dash.

8. *The Fourth Correct Dash.* The actions during the third space are the same as during the first and second spaces. When the fourth dash has lasted 3½ seconds, it sets up relay L. At the termination of the fourth correct dash, relay M is operated and rings the alarm through the circuit:

> Battery and charger, X, antenna switch, 24, alarm bells; radio room bell to 21; bridge and cabin bells to 3 and 4, SW-3, 5, 21; then all bells to contacts M-1, chassis, G, 16, to charger and battery.

Relay M also de-energizes relays E, F, G, H, J, and K of the counting system, also relay C, by opening their circuits to battery. Clutches CL-1 and CL-2 are thus released, and this condition continues until relays L and M are released by the "Release" push-button, SW-6, which opens the circuit:

> Battery and charger, 18, antenna switch, 19, contacts D-2, cam contacts IV-1, winding of relay L, contacts L-1, winding of relay M, SW-6, 16, to charger and battery.

9. *Operation Through Interference.* The selector will operate to select the auto alarm signal from a considerable amount of interference, caused either by other stations or by atmospherics provided:

(a) The interference does not combine with the desired signal so as to actuate relay B for periods in excess of 4½ seconds' duration.
(b) The interference does not completely fill in the interval between the dashes of the auto alarm signal.

The presence of interference immediately preceding or immediately following the dashes of the auto alarm signal have the effect of lengthening those dashes. If the lengthened dash remains less than 4½ seconds in duration, the selector will accept it as a dash of correct length. If lengthened beyond $4\frac{1}{2}$ seconds' duration, it and any previous registered dashes will be rejected as described in paragraph 4.

> Interference which exists during the interval between dashes of the auto alarm signal but does not completely fill that interval will operate relay B which, in turn, operates relay C and starts the rotation of cams $4\frac{1}{2}$ and $3\frac{1}{2}$ as for a dash, paragraph 3. If the interference ceases before the $1\frac{1}{2}$-second period expires and before the end of the silent interval of the signal, relay B will open releasing relay C, thus returning cams $4\frac{1}{2}$ and $3\frac{1}{2}$ to their rest or zero position, ready to receive the next dash. Since cam $1\frac{1}{2}$ has not yet operated its cam contacts IV, any record of previous dashes existing in the counter will remain intact. Interference which completely fills the silent interval acts to prolong the preceding dash beyond its limit of $4\frac{1}{2}$ seconds.

The transmitting cam together with its cam controls V–1 and one pole of the SIG. TRANSMIT switch may be used in connection with a suitable keying relay to operate the ship's transmitter for the correct transmission of the auto alarm signal. The other pole of the switch completes the motor circuit to battery removing the necessity of shifting the antenna switch.

There are auxiliary contacts on the motor governor which operate when the speed becomes too slow and operate the alarm bells through the circuits:

> Battery and charger, X, antenna switch, 24, alarm bells, radio room bell to 21; bridge and cabin bells to 3 and 4, SW–3, 5, 21; then all bells to motor contacts 4, chassis, G, 16, to charger and battery.

There are overrun contacts adjacent to the dash and space cams. Should the clutches fail, for any reason, to release either of these cams, the cam will overrun and open its associated overrun contacts. This stops the motor, thereby causing the alarm bell to ring. The motor circuit is as follows:

> Battery and charger, 18, antenna switch, 19, SW–5, motor terminal No. 2, motor terminal No. 1, VI, VII, 16, charger and battery.

Spark suppressors have been incorporated across the terminals of the two clutch windings to eliminate interference in the receiver from these circuits.

10. *Antenna Switch.* The 107A antenna switch in the Marine Unit is arranged to transfer the ship's main antenna from the normal ship radio equipment to the auto alarm receiver and put the auto alarm equipment into operation.

The blade of the antenna switch, insulated for high voltage, transfers the antenna. Auxiliary contacts, operated by the movement of the antenna blade, supply power to the receiver and selector units and also complete the circuit to the alarm bells.

No test whatsoever of the alarm equipment can be made without the antenna switch being closed on the auto alarm position, the closing of that switch completing automatically the power circuits of the entire apparatus.

With the switch in DF-AA position, an auxiliary receiving antenna is connected to the ship's regular receiver. When in DF-AA position, the direction finder on the bridge is made operative only if the grounding switch is pushed in.

11. *Alarm Bells.* The three alarm bells necessary with this equipment are mounted one in the Marine Radio Unit, one on the bridge, and one in the radio operator's quarters. The bells mounted on the bridge and in the operator's quarters may be temporarily cut out of circuit during routine tests by means of the nonlocking push button on the receiver marked "Bridge Bell Off."

12. *Warning Lights.* Two warning lights, one mounted above the receivers in the Marine Radio Unit and one on the bridge, serve to indicate that the equipment is inoperative because of prolonged noise or static, or both, or the reception of a signal longer than $4\frac{1}{2}$ seconds' duration, and which is of sufficient magnitude to maintain the signal relay in its "operated" position. These lights also indicate the failure of the ship's 115-volt power supply to the radio room during the time that the auto alarm equipment is in operation. Such failure of the ship's power will automatically transfer the receiver to the auxiliary 90-volt B battery and will also interrupt the charging of the storage batteries.

13. *Auxiliary Equipment.* (a) *Storage Batteries.* This equipment is supplied with two sets of 24-volt storage batteries which supply power for the operation of the heaters of the receiving tubes, the timing motor and clutches, the counting relays, the alarm bells and the warning lights. They are connected to the battery charger so that one set may be charged while the other set is being discharged. The normal drain from the batteries is 1.4 amp, each set of batteries being rated at 50 ampere-hours capacity.

(b) *Battery charger.* The battery charger supplied, which is a part of the Marine Radio Unit, operates from the ship's 115-volt d-c lines. A four-pole double-throw switch is supplied on the charger panel by which the batteries may be alternately charged and discharged. This switch, labeled AUTO ALARM BATTERIES, provides for the selection of the battery to be used, the other being placed in the charging circuit under control of the toggle switch marked AUTO ALARM CHARGER. This switch, when thrown, charges the battery at approximately 2 amp. It also operates the ventilating fan at low speed. The circuits of this switch are so arranged that the two sets of batteries discharge in reverse direction through the equipment, although both are charged in the proper direction. This is done in order to reverse the direction of current flow through the motor governor contacts, thereby greatly reducing the tendency for those contacts to become pitted. Separate fuses are provided for the discharge circuits, a 6-amp fuse for the alarm bell circuit and a 3-amp fuse for the rest of the equipment. These fuses are placed inside the selector cabinet and are accessible by opening the front of the selector.

(c) *Receiver power supply unit.* Plate circuit power for the receiver is obtained from a receiver power supply unit which takes power from the ship's 115-volt d-c lines and properly filters it for this use. This unit is placed in operation by throwing the right-hand switch on the Marine Unit directly over the main receiver, labeled AUTO ALARM POWER SUPPLY. A green light, mounted beside the switch lights, indicates that the power supply is operating. One-ampere fuses in the base of the MARINE UNIT provide protection for the power supply. The unit is mounted on the back panel of the right-hand base section of the Marine Unit behind motor generator 120A. A relay is provided which is so adjusted and arranged that it will transfer the receiver circuits for operation from the auxiliary 90-volt dry B battery, should the voltage of the ship's d-c line fall below approximately 70 volts. When this transfer to B battery operation is made, this relay also completes the circuits of the warning lights on the bridge and on the Marine Unit to indicate both that operation is from the auxiliary batteries and that the charging of the 24-volt storage battery has stopped or is greatly reduced through this lowering of the line voltage.

(d) *Auxiliary 90-volt B battery.* The Marine Radio Unit is provided with a 90-volt dry B battery for use, as explained above, during such times that the ship's 110-volt d-c power is not available in the radio room. This battery consists of two 45-volt units of the usual type generally available for this use. These batteries are mounted in the top rear of the right-hand base section.

14. *To Place Auto Alarm Equipment on Watch.* After the closing of the manual radio watch in the usual manner, the auto alarm shall be placed in operation by following the procedure herein outlined.

(a) Throw the AUTO ALARM BATTERIES switch to either side, so as to connect 24-volt battery to auto alarm equipment. Throw AUTO ALARM CHARGER switch ON to charge second battery. Turn ON receiver power supply unit.

(b) Transfer antenna switch 107a to auto alarm position DF-AA, thereby transferring the ship's main antenna to the auto alarm receiver, starting the auto alarm equipment, and connecting the auxiliary receiving antenna to the ship's receiver.

(c) After allowing thirty seconds for the tubes to warm up, set the sensitivity control at about 6 and test the auto alarm by depressing the TEST BUZZER push button on the receiver to form a series of dashes simulating the alarm signal, at the same time depressing the BRIDGE BELL OFF push button, thereby opening the bridge alarm bell circuit.

Note: Under conditions of no interference, the alarm bell should operate after four dashes. Under conditions of interference, it may require more than four dashes to operate the alarm bell.

Once every twenty-four hours, the auto alarm shall be tested with the bridge bell *in the circuit.*

(d) Upon satisfactory indication that the auto alarm is in operating condition, i.e., sounding of the alarm bell in response to (c) above, adjust the sensitivity control to OPTIMUM as described in paragraph 20a below.

(e) Notify the officer on watch on the bridge that the auto alarm has been tested and is operating satisfactorily.

(f) Make appropriate entries in the ship's daily radio log and in the auto alarm log to the effect that the auto alarm has been tested and put in operation and that the officer on watch on the bridge has been notified, giving the time in each case.

(g) Make entries in the auto alarm log giving the sensitivity control setting and readings of the A and B voltages at the receiver panel meter.

15. *To Take Auto Alarm Equipment Off Watch.*

(a) Transfer the antenna switch to one of the radio operating positions, thereby stopping the auto alarm equipment.

(b) Turn receiver power supply unit OFF and take second battery off charge by opening charger, toggle switch, or continue either battery on charge depending on their condition.

(c) Resume manual watch in the usual manner, making appropriate entries in the ship's daily radio log and in the auto alarm log.

16. *On Sounding of the Alarm Bells.* (a) *True alarm.* Upon the reception of a true alarm, the bells will ring. The operator shall proceed immediately to the radio room and depress the RELEASE KEY on the selector panel to stop the bells' ringing. The antenna switch should be transferred to the MAIN OPERATING position and manual watch opened, carefully searching the 500-kc band for indication of distress signals. Appropriate entries shall be made in the ship's daily radio log and in the auto alarm log and, in addition, the ship's radio log shall give details of the distress, including full text of the distress traffic heard or worked.

(b) *False alarm.* Upon determining that the alarm bells have sounded a false alarm as determined by subsequent investigation of the 500-kc band, the auto alarm shall again be placed in operation as previously outlined in paragraph 14, including the testing of the auto alarm and notification of the officer on watch on the bridge. Appropriate entries shall be made in the logs.

(c) *Equipment out of order.* Should the alarm bells ring because of failure of the equipment, as outlined previously, this alarm may be distinguished apart from a true alarm or a false alarm inasmuch as depression of the RELEASE KEY *will fail to stop the ringing of the alarm bells.* The auto alarm should be taken out of operation and thoroughly checked for faults as outlined in paragraph 22.

Upon location and correction of the trouble, the auto alarm shall again be placed in operation and on watch, as was outlined in paragraph 14, making appropriate entries in the logs and in addition an entry in the auto alarm log covering the nature of the failure and the remedies applied.

17. *On Operation of Warning Lights.* A continued burning of the warning lights on the bridge and in the radio room is an indication that:

(a) The signal relay has become locked up because of a sustained signal or continuous static or noise of such high strength as to have the same effect, or indicates that:

(b) The ship's 115-volt d-c supply to the radio room and receiver power supply unit has failed or has been reduced materially, thus transferring the receiver to operation from the auxiliary B batteries.

When (a) occurs, the sensitivity control should be reset to the "optimum" adjustment in accordance with paragraph 20d.

When (b) occurs, steps should be taken to have the ship's power resumed.

An entry shall be made in the auto alarm log by the operator and in the ship's official log by the officer on watch on the bridge whenever adjustments are necessary to reduce the sensitivity of the auto alarm giving all pertinent details.

18. *Date Labels.* In accordance with Federal Communications Commission instructions, all batteries and tubes used in auto alarms shall be date-marked, showing their length of service. A number of gummed labels have been supplied for this purpose. Each tube and dry battery shall be labeled and marked with the date when it was actually placed in service (*not* when received aboard ship), and with the date it was removed from service.

19. *Log Entries.* Entries should be made by the operator in the ship's daily radio log, and by the officer on watch in the ship's official log, of the daily tests of the auto alarm, giving the time and other pertinent details. In addition, an auto alarm log shall be maintained giving the times the alarm was placed on watch, taken off watch, and any incidents such as true alarms, false alarms, or other pertinent details.

Statements shall also be made in both logs whenever the warning lights remain lighted for a continuous period of five minutes, giving particulars as to the time the operator was called to make the necessary repairs or adjustments, the reason for the failure, the names of any parts removed, added, or substituted and the time the alarm was restored to proper working conditions.

20. *Operating Instructions.* (a) *How to start auto alarm equipment.* Turn AUTO ALARM BATTERIES switch to position to discharge desired battery. Turn power supply unit ON as indicated by the green pilot light on the panel. Shift the antenna switch to the auto alarm position, thereby transferring the main antenna to the auto alarm receiver and completing the power circuits to the equipment. Close the toggle switch of the battery charger, thus charging the second 24-volt battery. After approximately 30 seconds are allowed so that the tube heaters can warm up, the auto alarm should be in operating condition.

Note: The charging rate has been adjusted to such a value that the batteries will be returned to the fully charged condition if they are charged one hour for every hour of discharge. The battery on discharge should be alternated every 24 hours rather than each time the equipment is placed on watch, unless this occurs only once per day, as this will result in a more equal division of operating time between the two sets.

(b) *How to send buzzer test signals.* Press the button marked TEST BUZZER on the receiver unit, thus operating the buzzer which generates the signals.

(c) *How to check receiver sensitivity.* Press the TEST BUZZER button and turn the SENSITIVITY CONTROL knob counterclockwise until the meter on the receiver panel averages 5 ma. The SENSITIVITY CONTROL knob setting should be approximately 5. As the sensitivity of the receiver becomes less and less, because of weakening of the tubes or for other reasons, the meter reading of 5 ma will occur at higher and higher settings of the sensitivity control.

(d) *How to adjust sensitivity control to "optimum."* The "optimum" setting of the sensitivity control is the highest to which the control can be turned toward maximum (scale reading of 10) under the existing conditions of noise or static, or both, and including the normal background of weak signals, without causing the milliammeter needle to hover at a higher reading than about 3 to 4 ma. It is the adjustment of the sensitivity control at which the signal relay and the dash clutch are not energized except momentarily by the noise or static during periods of no-signal. Generally this adjustment will occur somewhere between the scale readings of 5 and 10. This adjustment will generally be at a higher value during daylight periods than at night.

Care must be taken that the setting of the sensitivity control is not *too low* as this will result in the receiver being insensitive and thereby less likely to receive an alarm signal. Continued operation of the receiver in an insensitive condition not only defeats the purpose of the auto alarm equipment, *but it might also subject the vessel and its officers to embarrassment should the equipment fail to respond to an alarm sent out by a near-by vessel in distress.*

The proper adjustment of the sensitivity control will be made considerably easier with the aid of headphones plugged into the "phones" jack on the receiver.

(e) *How to stop alarm bells.* If the alarm bells are ringing because of the reception of a *true alarm signal* or because of a false alarm signal, the bells will be stopped when the RELEASE KEY on the selector unit panel is pressed. If, however, the bells do not stop ringing when this button is pressed, their ringing is caused by some failure of the equipment and they will only cease when the failure is remedied or the auto alarm equipment is turned off. The failures of the equipment which will cause the bells to ring include:

Burning out of a vacuum tube heater.
Storage battery voltage becoming too low.
Selector fuse in selector unit blown, or the 24-volt circuit to auto alarm equipment open.
Motor stopped or running too slow.
Vacuum tube heater circuit or 24-volt circuit to receiver open.
Ground on alarm bell circuit.
Magnetic clutch failed to release cam, stopping motor by opening overrun contacts.

(f) *When warning lights operate for extended periods.* The warning lights operate whenever the signal relay is operated continuously for periods longer than 4½ seconds and are extinguished whenever the signal relay is released. Such operations of the relay can be due to the reception of a long dash but the relay can also be held in the operated position by strong noise or static conditions. The remedy is to reduce the sensitivity of the receiver to its "optimum" value as explained in (d).

These warning lights also operate when the ship's d-c power to the receiver power supply unit (B battery eliminator) either fails or falls below 70 volts, thereby automatically switching the receiver to the auxiliary B batteries.

(g) *How to read battery voltages.* The voltmeter on the selector unit panel is provided with a three-position switch so that the voltages of the two sets of 24-volt batteries, the output of the receiver power supply unit, and the auxiliary 90-volt B batteries can be measured.

Position "Minus A" indicates the voltage of battery no. 1 when on discharge (positive side of battery *grounded*).
Position "Plus A" indicates the voltage of battery no. 2 when on discharge (negative side of battery *grounded*).
Position "Plus B" (nonlocking) indicates the voltage of the output of the receiver power supply unit when that unit is turned ON and it is operating. If the meter reading for this position is *backward,* it indicates that the ship's 115-volt d-c power to the radio room has been reversed and should be corrected.
Position "Plus B" (nonlocking) indicates the voltage of the 90-volt auxiliary B battery when the receiver power supply unit is turned OFF.

(h) *How to stop auto alarm equipment.* Shift antenna switch from the auto alarm side to the "Main Position," thus connecting the antenna to the normal radio equipment. Turn off the receiver power supply unit. Open AUTO ALARM CHARGER switch to stop charging of battery unless it becomes necessary to continue charge for any reason.

(i) *General operating notes.* Allow approximately thirty seconds or more after starting the auto alarm equipment for the heaters of the tubes to warm up so that the receiver can become operative.

When testing the alarm with dashes from the buzzer, headphones should be used to monitor the receiver in order to note any interference which may be present. With no interference present, the bells should ring after four correctly timed dashes have been applied to the receiver. During times of interference, it may require more than the minimum of four dashes to operate the bells, depending upon the manner in which the interference combines with the alarm signal to spoil the timing of the latter.

This receiver has been designed for the specific purpose of operating a relay from the received signals. It was *not* designed for the aural reception of signals. Therefore, the signals heard in the headphones during monitoring will have a peculiar sound or quality, making the receiver somewhat inefficient for headphone use. Do not be misled, therefore, in judging its capabilities by what you hear in the phones.

21. *Maintenance.* In order that electrical and mechanical equipment operate at its maximum efficiency, it must be given attention periodically. The auto alarm is such a piece of equipment and should be cared for in the following manner:

(a) *General.* The entire equipment should be kept *clean* and free from dust and foreign matter. All connections and mounting screws should be checked periodically for tightness. Spares when used should be replaced as soon as possible. All routine tests should be faithfully performed with particular attention given to evidence of failure of any kind.

(b) *Tubes.* The operator in charge of the equipment should acquaint himself with the normal response of the receiver by means of headphones plugged into the phone jack in order that he may detect any subsequent weakening of the tubes in the receiver. In addition, he should note the setting of the sensitivity control at which the milliammeter on the receiver panel averages a 5-ma reading on test buzzer signals when the line voltage is normal for the particular installation. Further check may be obtained by setting the sensitivity control in the above manner and then substituting a new tube in each position in rotation, noting the milliammeter reading for each substitution. A pronounced increase in reading will then indicate when a weak or defective tube has been replaced.

(c) *Relays.* All relays and contact springs should be handled with care so as not to change their adjustment or tension. All relay and timing cam contacts should be polished with the burnishing tool supplied for this purpose once a month, or oftener should this prove desirable for particular installations.

Special attention should be given relays B and C. The process of burnishing is carried out in the following manner: *Remove all power* by opening the 24-volt battery circuit at the AUTO ALARM BATTERIES switch on the panel; turn OFF power supply unit and also open the B battery by removing one lead from the battery. Otherwise a contact may be damaged by an accidental short circuit. Carefully insert the blade of the burnishing tool between the contacts to be polished and work the blade back and forth between the contacts 25 or more times while gently pressing the contacts against the blade with the fingers of the other hand. Do not exert too strong a pressure as this is a *polishing* process and not a filing one. *Do not use a file of any kind on any relay or cam spring contact.* Do not follow up the burnishing process with an attempt to clean the contacts with rags or paper strips, etc. To do so merely leaves lint or foreign particles on the contacts which will burn and cause future trouble. Relay contacts, when fully "made" should be deflected from their free position by about 0.005 inches. Observe the contact movement of a new or properly operating relay. Relay springs or armature adjustments should never be changed unless it is absolutely necessary for regaining proper operation.

(d) *Motor.* The motor is equipped with self-oiling ball bearings and a reduction gear running sealed in grease. It should not require oiling except after extended use and then only by competent servicemen from the service depots. Experience has shown that the motor governor rings and brushes require periodic cleaning, at least once a month, for uninterrupted operation of the motor.

To clean the governor rings, it is necessary to remove the governor plate from the motor shaft. This is done in the following manner:

Remove the top cover plate of the motor.

Remove the one-half inch screw plug cover of the governor compartment.

Insert a small screwdriver through the screw plug hole and loosen the two set screws that hold the governor plates to the motor shaft. The governor plate can then be lifted from the motor shaft. In replacing the governor plate, care should be taken to avoid damaging the governor brushes. This can be done by carefully placing the brushes in the holders before lowering the governor plate on the motor shaft.

Should the governor rings and brushes or the motor commutator and brushes require any attention, merely *clean them* with a cloth, together with the brush holders. A solvent, such as a small amount of carbon tetrachloride, benzene or alcohol may be beneficial in some cases. However, care should be taken not to scratch the contact surface of the copper. *Never use any kind of abrasive on the commutator or governor rings.* If the governor contacts become pitted, they may be smoothed by a very fine file or a fine sandpaper, followed by a thorough burnishing with the burnishing tool to regain their polished surface. After doing this, it may be necessary to readjust the speed of the motor. This is done in the following manner:

The slow-motion shaft of the selector should revolve at a speed of 6 rpm, which is 1 revolution per 10 seconds or ½ revolution every 5 seconds. If the speed of the motor is correct, then the transmitting contacts will be opened by the cam on the end of the slow-motion shaft every 5 seconds as observed by the second hand of the radio room clock. If the speed is too *slow*, removed the cover of the governor compartment on top of the motor and turn the small spring contact adjusting screw in one-quarter turn and recheck the speed. Adjust this screw until the motor speed is correct, which is that adjustment where the shaft makes 6 full revolutions in 59 to 61 seconds.

(e) *Cam Assembly.* The cam contacts should be burnished as specified for relays in (c) above. *See that the small bakelite bushings between the ends of the contact springs are not displaced* or lost. A small oil hole is provided on the upper side of the two cams. *One drop* of light oil should be applied once every 3 months. The collector rings on the two clutches should be wiped clean with a clean cloth occasionally, and the brush springs examined for tension and for wear. *These brushes should bear firmly upon the rings.* The cam contact operating springs, with the V bend on the end which engages the cam, should be examined periodically for wear. The slow motion shaft bearings are sealed, self-lubricating ball bearings and require no attention.

(f) *Receiver power supply unit.* Requires no maintenance except the switching relay, which should be burnished in the manner specified in (c) of this section.

(g) *Storage batteries.* The storage batteries of this equipment are similar to any other storage batteries used with radio equipment and should receive the same attention. They should be kept clean, filled with distilled water and properly charged. The charging rate has been set to the correct value to recharge the batteries in one hour for each hour of discharge. They should be given a periodic overcharge in order to equalize the batteries and keep them in proper condition. (Refer to section on care of batteries, elsewhere in this book.)

(h) *Dry B batteries.* The voltage of the dry B batteries should be checked each week *under load,* that is, after being placed in operation by leaving the power supply unit switch OFF for a period of 5 minutes. Batteries should be replaced with fresh ones as soon as practical after their voltage, as measured above, drops to 75 volts.

22. *Correction of Faults.* The following is an outline of faults which might occur in the auto alarm equipment, together with methods of correcting them. This outline is not intended as a complete listing but merely as a guide to aid in the servicing of this equipment and maintaining it in operation.

(a) *No signals from receiver*

Ship's d.c. reversed, thus placing negative side on plates. Check by turning power supply unit OFF and noting action of voltmeter with its switch held on B.

R-f amplifier tube grid lead off or grounded. Dirty contacts on relay A.

(b) *Signals in phones but no relay action*

Defective 89 rectifier tubes.
Shorted condenser, C11.
Open milliammeter.

(c) *High noise level locking up relay*

If noise stops when antenna is disconnected, source is external to equipment and should be located and corrected, if possible.

If noise continues, source is in equipment or from ship's d-c line.

If noise continues when receiver power supply is turned OFF and toggle switch on battery charger opened, the source is in equipment. Check all connections for their tightness, clean motor commutator and brushes as per (d) under Maintenance.

(d) *Defective audio transformer*

Temporary repairs may be made either by jumping out the defective stage or by utilizing the remaining good winding of the transformer by using it as choke and reconnecting the stage as an impedance-coupled stage.

(e) *Signal relay operates but no selector operation*

See that dash cam returns against its back stop and completely operate cam contacts below the cam. If necessary, increase cam return spring tension by loosening the three screws holding clamping ring around the knurled shoulder next to motor shaft coupling and then rotate knurled shoulder counterclockwise a portion of a revolution, again tightening the clamping ring screws.

Examine these bottom cam contacts and see that they are "making" properly. These contacts must close before the signal relay can operate relay C and in turn the dash clutch. See description of operation under heading "The First Dash."

(f) *Space cam does not operate*

Contacts III-1 of 3½ second cam dirty, or not closing. Back contacts of relay M-2 dirty or not making. Contacts of relay E-1 dirty or not making. Clutch collector ring brushes dirty or not enough tension.

(g) *Counting relay operation OK but bells do not ring*

If relay M does not lock up, release key may be stuck. If relay does lock up, contacts M-1 may be dirty, alarm fuse on battery charger blown.

(h) *Alarm does not ring after four test dashes*

When the alarm receiver is connected to an antenna, external signals may combine with the test signals in such a manner that the combination will act to spoil the timing of the test signal. The headphones should be worn during test of the auto alarm equipment in order to make certain that when additional dashes, beyond the normal number of four, are required that it was because of the presence of interference.

(i) *Erratic registering of correctly timed signals*

If some correctly timed dashes may be registered in the counter while others are not, with no interference present, check motor speed, relay B contacts, relay C contacts, dash clutch collector rings and brushes for proper operation.

(j) *Motor speed suddenly much too high*

Governor contacts pitted and welded closed; governor contacts shorted out of circuit.

(k) *Motor speed much too slow*

Governor contacts dirty; governor brushes dirty, stuck in holder, worn too short.

(l) *Alarm bell does not operate*

Remove from housing and burnish contacts thoroughly.

(m) *Buzzer does not operate*

Dirty or burned contacts; contacts out of adjustment, series resistor open; buzzer button not making proper contact. Buzzer is adjusted by screw at bottom, backing it out at least ½ turn from point where it merely clicks, until a smooth note and steady meter reading is obtained.

(n) *Alarm bells operate because of equipment failure*

The source of the trouble can be located most easily through the following procedure:

(1) Observe voltmeter, if no indication of voltage on positions − A or + A; check selector fuse (3A fuse in selector unit).
(2) If voltmeter indicates some voltage on above position, note whether it is normal 24 volt reading. Battery may be nearing complete discharge.

(3) If voltmeter shows normal 24-volt reading, open selector cabinet and note whether motor is operating at normal speed.

(4) If so, open receiver cabinet and observe whether relay A is operated, indicating the heater circuit complete.

(5) If motor is not running, observe whether one of the clutches has failed to release its cam, thus opening one of the pairs of overrun contacts. If so, check operation of cam contacts II and IV, also relays D, E, and F, together with their contacts.

(6) If above steps do not indicate location of failure, check bell circuits for grounding by removing the bell leads, one at a time, from terminals No. 3, No. 4, and No. 21, a ground on any one of which leads will cause all bells to operate.

(7) If the failure still remains, replace above leads and then remove lead from terminal No. 5. If bells continue to operate trouble is in receiver alarm bell circuit wiring of relay A. If failure stops, trouble is in selector alarm bell circuit wiring or in motor alarm contacts, or in Relay M.

A similar process of elimination, after a study of the circuit diagram, will assist in locating the source of any trouble which might appear with this equipment. The bridge and operator's cabin bells may be removed from the circuit and thereby prevented from ringing and causing unnecessary disturbance during the above tests (except for the tests of (5) above) by removing the leads from terminals No. 3 and No. 4 in the receiver cabinet.

(o) If it becomes necessary to operate the auto alarm receiver from the auxiliary B battery for any reason, the circuit from the power supply unit relay to the warning lights should be opened by removing the lead from terminal No. 50 in the power unit, taking care that the lead does not become grounded. This lead should be reconnected when operation from the power unit is resumed.

23. *To Transmit an Auto Alarm Signal.* Upon receiving orders from the Captain, or other authorized officer of the vessel, to permit an auto alarm signal (which precedes the SOS distress signal), proceed as follows:

With the antenna switch turned to connect the i-f transmitter to whichever antenna it is desired to use, place the transmitter in operating condition on 500 kc, adjusted for a broad signal (in the manner called for in the Regulations for transmitting a distress signal), close the AUTO ALARM BATTERIES switch on the panel and turn ON the switch marked SIGNAL TRANS, on the auto alarm selector panel. This starts the selector motor independently of the rest of the auto alarm equipment and completes the key circuit. Contacts in the selector will then operate the transmitter keying relay to transmit correctly time alarm signals of 4-second dashes and 1-second spaces between dashes. *To stop transmission,* it is only necessary to turn OFF the SIGNAL TRANSMIT switch on the selector panel.

24. *List of Spare Parts.* Each auto alarm installation is supplied with spare parts assembled in a suitable container. Whenever items are used from the box, the contents of the box should be replenished at the first opportunity.

13–1e. Mackay Radio Receiver 128AV (Component of FT–106 Marine Radio Unit)—Radio receiver 128AV has been designed primarily as a marine radiotelegraph receiver but is also well suited for many applications on land. It covers the intermediate- and low-frequency bands and is designed for reception of both CW and modulated signals. The complete frequency coverage is 15 to 650 kc, divided into four overlapping ranges:

Range A	15–41 kc
Range B	37–105 kc
Range C	95–260 kc
Range D	240–650 kc

The full-vision tuning scale is calibrated in kilocycles for each of the four ranges.

1. *Electrical Design.* The schematic circuit diagram is shown in Figure 13–8. The receiver has one stage of tuned radio-frequency amplification, a regenerative detector, and two stages of audio-frequency amplification. The tuned coils are marked L1 to L10 inclusive and the range selector switch consists of two ganged switches S2 and S3. Antenna switch S1, when thrown to the MAIN position, connects the antenna to the primary coil of L1, L2, L3, or L4 according to the range (A, B, C, or D) in use. When in the EMERG position, the antenna is connected to an extension terminal E on the cabinet terminal board, to which the antenna lead from the 123–BX crystal receiver is to be connected.

Assuming the selector switch is on range B, coil L2 is connected to C1A and C1B in parallel, the front two gangs of the tuning condenser. Shunted across C1A is antenna trimmer C2, controlled from the front panel. L2 is also connected to the grid of the r-f amplifier tube V1. The plate of V1 drives coil L8 through its primary winding. Coil L8 is tuned by C1C and C1D in parallel, the rear two gangs of the tuning condenser, forming the detector tuned circuit. The detector V3 utilizes grid leak R11 and condenser C14. A separate regenerator tube V2 is used, whose plate is coupled back to L8 through a tickler winding. Two stages of resistance coupled a-f amplification, tubes V4 and V5, follow the detector. The output of V5 is coupled to the phone jacks by means of choke L12 and condensor C26.

The gain of the r-f amplifier is controlled by potentiometer R1, acting on the cathode potential of V1. Potentiometer R2 controls the degree of regeneration by adjustment of the plate voltage of V2. Audio frequency gain is controlled by potentiometer R3 in the grid circuit of V5. Resistor R15 in the detector plate output, together with condenser C20, act as a filter to reduce the amount of r-f signal passing from the detector into the a-f amplifier. Resistor R10 and condensers C10 and C11 constitute a scratch filter on the regeneration control.

On range A, the receiver functions in a manner similar to that on range B. On ranges C and D, two tuned circuits are used between the antenna and the grid of the r-f amplifier. For instance, on range D the antenna signal current drives L4 which is tuned by C1A. This circuit is coupled to the circuit including L6 and C1B by means of the common condenser C5. Resistor R4 gives a d-c path around C5 to the grid of V1. A trimmer C4 is used to track the r-f grid circuit L6, C1B with the detector grid circuit. The detector grid circuit comprises L10, tuned by C1D and trimmed for frequency tracking by C36. Condenser gang C1C is not used on ranges C and D. The range selector switches are provided with segments which short circuit the primary and secondary coils or ranges not in use, in order to avoid dead spots due to self-resonance of the low-frequency coils.

2. *Operation.* To operate the 128AV receiver, turn the receiver battery charge-discharge switch labeled RECEIVER BATTERIES on the panel of the Marine Radio Unit to either side according to which battery is to be used. Turn the HEATER switch in the lower left corner of the receiver panel to BATTS. The PLATE switch should be turned to LINE, and the POWER switch immediately above turned ON. The pilot light labeled POWER will light, indicating that power is available from the ship's line. If there is no power available from the ship's line, turn the PLATE switch to BATTS. Turn the ANTENNA switch to MAIN. Set the AF GAIN and RF GAIN controls at least halfway to maximum. Set the range switch ABCD to the proper range and the tuning dial to the desired frequency. Turn up the REGENERATION control just above the oscillation point, where a slight click is heard in headphones plugged into the PHONE jack. The signal may now be trimmed up by means of the main tuning dial and the ANTENNA TRIMMER. The gain controls can be adjusted for the desired intensity. When receiving modulated signals, the REGENERATION control may be turned just below the point of oscillation.

In the event that it is desired to use the 123-BX crystal receiver, turn the ANTENNA switch to EMERG and follow the instructions for that receiver. It is not necessary to have the 128AV receiver turned on when using the 123-BX.

3. *Maintenance.* To renew tubes, fuses, and dial lights, the panel-chassis assembly must be removed from the shield. To accomplish this, remove the two 10-32 screws at each end of the panel. The chassis is stamped adjacent to each socket with the type of tube required in that socket. Either the metal type tubes, or the glass type may be used.

The fuse amperage is stamped beside each fuse post. The fuses are type 3AG. The two dial lights are type 47.

(a) *Circuit check.* The value of each resistor and fixed condenser can be determined from the parts list, in conjunction with the schematic diagram. There is shown on the diagram views of the under side of the socket for each type of vacuum tube, with the prongs or pins numbered 1 to 8 in conventional manner, and with identification of the electrode connected to each pin. The following table indicates the proper voltages for each socket prong as measured from the chassis. The voltages shown are for all tubes in place, using a 6 volt A battery and 90 volt B battery. The chassis is negative in every measurement. For checking these voltages, remove the chassis from the shield and stand it on either end, leaving the battery cable plugged into the chassis. Use a 1000 ohms per volt meter. For measurements on tubes V3, V4, and V5, set regeneration just above the point of oscillation.

Prong	*V1*	*V2*	*V3*	*V4*	*V5*
1	0	0	0	0	
2	0	0	0	0	0
3	(a) (d)	(c) (d)	0	0.4 (e)	86
4	0	—	0	0	88
5	(a) (d)	0	0	0.4 (e)	0
6	(b) (d)	—	16 (d)	11 (d)	
7	6	6	6	6	6
8	90	0	23 (d)	14 (d)	9.0 (f)

(a) R-f gain max. 2.5 volts; r-f gain min. 31 volts.
(b) R-g gain max. 50 volts; r-f gain min. 62 volts.
(c) Regeneration max. 14 volts; regeneration min. 0 volts.
(d) Use 150-volt range.
(e) Use 7.5-volt range.
(f) Use 75-volt range.

(b) *Frequency calibration.* The accuracy of the frequency calibration of the tuning dial depends upon the inductance of the detector tuning coils, the capacitance curve of the tuning capacitor, and the minimum capacitance of the circuit. No attempt should be made in the field to adjust the coil inductance or the capacitance curve, as these adjustments require laboratory equipment. There is little likelihood that the factors determining the calibration accuracy will change spontaneously. In the event that an appreciable frequency error develops, the minimum capacitance of the detector circuits may be adjusted in the field. Trimmers are provided on both sides of the two rear gangs in the tuning capacitor and on the coil bracket for this purpose. Withdrawing the chassis from the shield for trimming will not change the calibration appreciably.

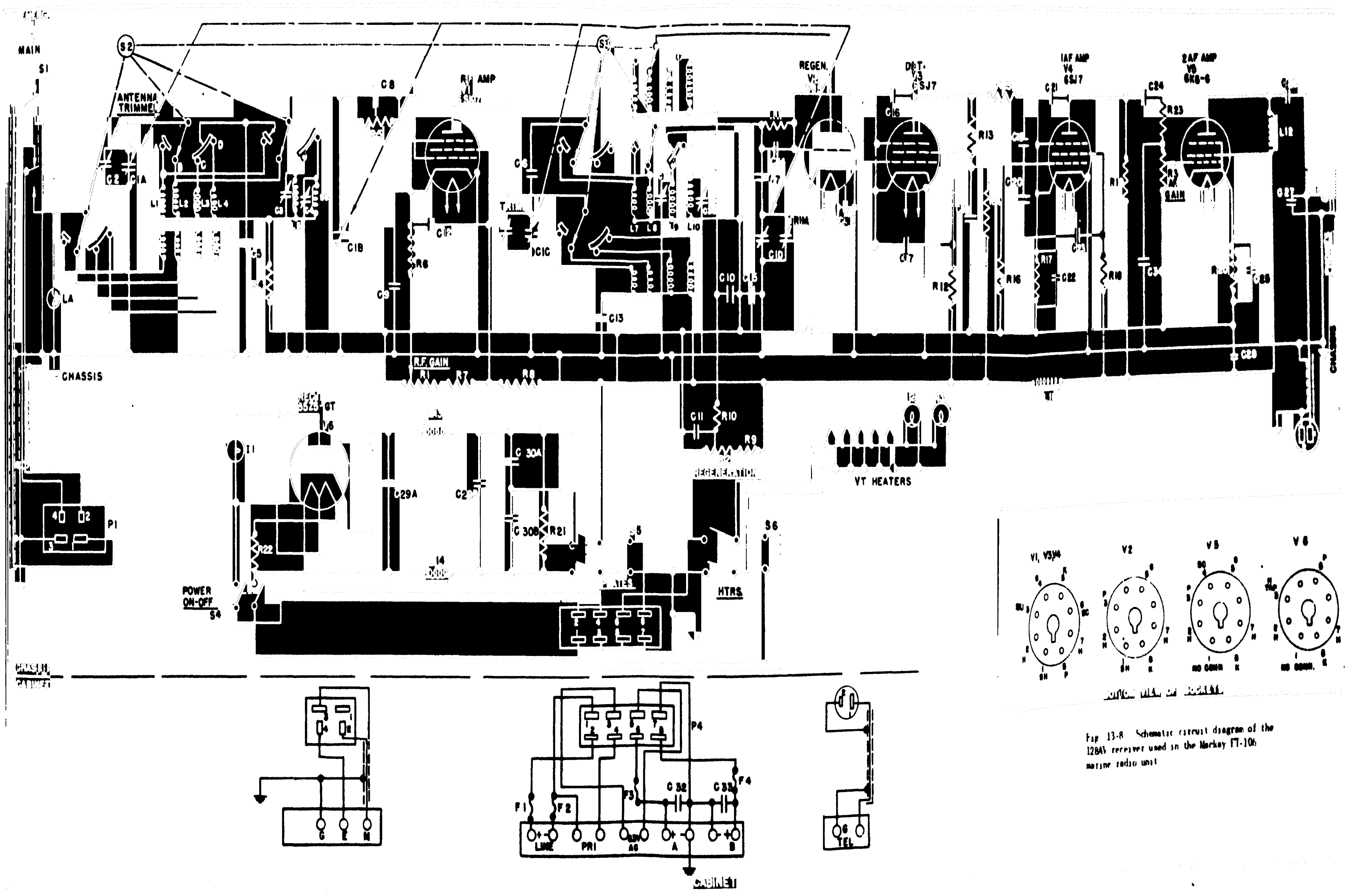


Fig. 13-8. Schematic circuit diagram of the 128AV receiver used in the Mackay FT-106 marine radio unit

Three signals are required, having a frequency accuracy of ½ of 1 percent or better, one being between 500 and 650 kc, the second between 200 and 260 kc; and the third between 80 and 105 kc. Tune in the highest frequency signal on range D, adjust the regeneration just above the oscillation point and the r-f gain at least ¼ turn below maximum. Adjust the trimmer on the rear gang and the one marked D on the rear surface of the coil bracket until zero beat is obtained with the dial set accurately to the known frequency of the test signal. Tune in the second frequency on range C and adjust for zero beat, using only the trimmer marked C on the rear surface of the coil shield. Proceed in the same manner for the lowest frequency signal, tuning it in on range B, and adjusting only the trimmers on the next to the rear gang.

If the dial calibration still appears to be inaccurate, the difficulty should be brought to the attention of an authorized service agent.

(c) *Trimming of the r-f grid circuit.* On each of the ranges C and D there are three tuned circuits. The frequency of the receiver is determined by the tuning of the detector circuit. The r-f grid tuned circuit is designed to track with the detector circuit. The antenna tuned circuit is provided with a manually controlled trimmer on the front panel. Two small trimming condensers are provided in the r-f grid tuned circuits: C3 for range C; and C4 for range D. These trimmers are adjustable with a screw driver through two holes in the top of the chassis, between the gang condenser and the panel, and marked with the letters C and D.

If these circuits appear to require trimming, withdraw the chassis from the shield, tune in a signal or background noise on the range D, in the region from 500 to 650 kc. Adjust the trimmer marked D for maximum response to the signal or noise. On range C, tune in a signal or background noise in the region from 200 to 260 kc and adjust the trimmer marked C for maximum response.

13–1f. Mackay Radio Receiver 123BX (Component of FT–106 Marine Radio Unit)—This is a simple crystal detector receiver intended for emergency shipboard use in case all other available receivers fail. The receiver is completely mounted on its front panel, which measures 6½ by 9½ inches. It is placed on the Marine Radio Unit panel at the left of the regular receiver, and may be completely removed by unscrewing the four panel screws, and disconnecting the antenna connection. The equipment mounted on the panel is shielded electrically and mechanically by a steel cover. If it is desired to gain access to the receiver parts, this may be done by removing the four screws which hold the cover in place.

The frequency range of this receiver is 350 to 550 kc. This receiver is responsive to any form of modulated signal, such as spark telegraph signals, A–2 (ICW) telegraph signals, or speech. Both antenna and closed circuit tuning are employed, resulting in selectivity which is very good for this simple form of receiver.

The schematic diagram of this receiver is shown in Figure 13–9. On the front panel, the tuning knob, the position of which may be read on the etched scale, controls the variable condenser in the antenna series tuned circuit. At the lower left corner is a knob controlling the three position tap switch for the antenna inductance. The secondary tuning condenser is at the lower right corner of the panel, varying from maximum to minimum in 180°. An OFF-ON switch, located at the upper right corner of the receiver panel, opens the antenna and shorts the crystal when in OFF position, thus protecting the crystal while transmitting or when the receiver is not in use.

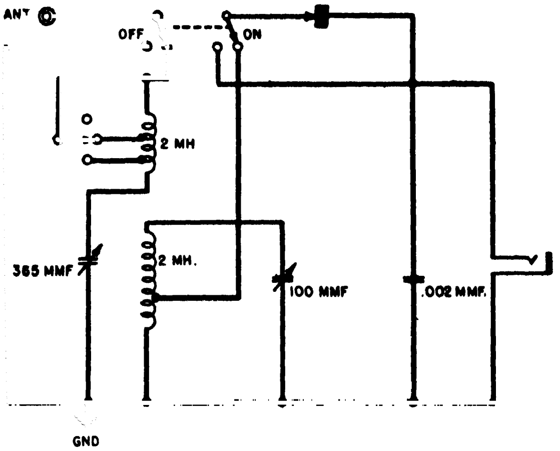


FIG. 13–9. Schematic circuit diagram of the 123BX emergency crystal receiver used in the Mackay FT-106 marine radio unit.

The receiver is connected to whichever antenna is in use, by placing the ANTENNA switch on the 128AV receiver in EMERG position. The crystal detector may be adjusted in an obvious manner to practically any part of its surface, in searching for a sensitive spot. In tuning in a station, the large tuning knob is the main factor in selecting the signals. However, the proper point on the antenna coil tap switch should be found by experience to get maximum sensitivity. This switch is provided to take care of various types of antenna installations. The secondary circuit tuning is much flatter than the antenna circuit, but gives considerable improvement in selectivity and sensitivity when tuned to the desired signal. Both tuning knobs turn clockwise for increasing frequency.

The Federal Communications Commission's rules require that a record of receiver adjustments be made on 500 kc, 375 kc, and one other working frequency between these two. For this purpose, a card holder is placed on the lower part of the 123BX receiver panel, on which should be recorded the required dial and knob settings.

13-1g. Scott Radio Receiver SLR-F (Component of FT-106 Marine Radio Unit)—The model SLR-F radio receiver is primarily intended for use aboard ship. It covers the frequency ranges of 80-560 kc and 1.9 to 24.0 mc in five bands, as follows:

Band 1	80-220 kc
Band 2	210-560 kc
Band 3	1.9-5.1 mc
Band 4	4.5-12.0 mc
Band 5	8.8-24.0 mc

The equipment is suitable for the reception of radio, telephone, or telegraph signals by either headphones or loud-speaker.

Special circuits and features are incorporated in the model SLR-F radio receiver to preclude its oscillator feeding voltages into the antenna circuit, and radiating interferences which could be detected by sensitive radio receiving or radio direction finding equipment.

The model SLR-F receiver is designed to operate from 110-volt, 60-cycle a-c supply, which is provided in the Marine Radio Unit from the ship's a-c line.

The model SLR-F receiver is mounted immediately below the 167AY transmitter in the left-hand section of the Marine Radio Unit. It is held in place by screws along each side of the front panel of the receiver and is connected to the Marine Radio Unit by means of flexible cables. These cables are of sufficient length to permit removing the receiver and placing it on the operating shelf of the Marine Radio Unit while repairs or minor adjustments are being made.

1. *Circuits.* The model SLR-F receiver is an 11-tube superheterodyne. The circuit employed on all ranges comprises one stage of radio frequency amplification, first detector, a separate high-frequency oscillator, two stages of the intermediate-frequency amplification operating at 585 kc, a diode type second detector, one stage of resistance coupled audio amplification, and an audio frequency output stage. The second detector utilizes one set of elements of a dual diode, the other set of elements is utilized for a peak noise limiter. The resistance coupled audio stage utilizes the triode section of a diode-triode tube; the two diode elements of this tube are connected in parallel and utilized for delayed automatic volume control. A beat-frequency oscillator is coupled to the second detector to provide for CW reception. A dual diode tube is connected between the audio-frequency amplifier tube and a power output tube, and is used as a limiter tube for CW reception to keep the audio output signal at a constant level.

The power supply section of the receiver, which is employed for supplying the necessary operating voltages for the receiver circuits, is designed for operation from 110-volt, 60-cycle, single-phase a-c power. The power supply includes a power transformer with r-f input filter and primary fuses, a vacuum tube rectifier, and a two-section a-f filter.

Two audio output circuits are provided:

(a) A phone jack is mounted on the front panel. The output from this jack can be adjusted to match the operator's phones by means of the jumper on the left side of the chassis. This load impedance can be adjusted for either 600 ohms or 20,000 ohms by inserting a jumper in the proper terminals. The output from this jack can be adjusted to suit the operator's desire by means of the screwdriver control on the left side of the chassis marked PHONE OUTPUT ADJ.

(b) Loud-speaker terminals are provided at the rear of the chassis. The correct load impedance of the speaker output circuit is 600 ohms.

An antenna input jack is located on the rear of the chassis and is connected by flexible cables to the terminal board mounted on the rear of the Marine Radio Unit.

The power lead and the phone leads for the time check circuit are also connected to plugs in the rear of the chassis of the model SLR-F receiver. Flexible cables running from these plugs are connected to the terminal board at the rear of the Marine Radio Unit.

Fuses which are located in the primary circuit of the power supply are mounted adjacent to the power input receptacle at the rear of the receiver chassis. The fuse mountings are of such design that the fuses, which are of the miniature cartridge type, are replaceable without difficulty.

2. *Antenna.* The input circuit of the SLR-F receiver is so arranged to be suitable for use with either a balanced feed line or a single-wire antenna system. The Marine Radio Unit has been designed for operation with a doublet receiving antenna and has therefore been wired to the receiver as a balanced feed line.

If, in an emergency, it is necessary to use a single antenna, a lead must be connected to the prong of the antenna plug which is adjacent to the chassis ground terminal and this lead must be grounded to the terminal. The antenna lead-in end then is connected to the remaining prong on the socket. The dimensions of a single wire antenna to be used in a receiver are not critical. The recommended minimum over-all length of the antenna lead-in is 75 feet. The recommended maximum over-all length is 200 feet.

3. *Construction.* The chassis assembly is rigidly secured to the front panel and forms a basic unit, capable of being inserted or withdrawn from the Marine Radio Unit as a unit. All vacuum tubes are accessible from the top side of the chassis, upon removal of the chassis from the Marine Radio Unit. The design and construction of the chassis assembly and the arrangement of the component parts

mounted thereon provide a high degree of accessibility to all items for inspection, servicing, or replacing. A bottom cover plate completely encloses the bottom of the chassis proper. It is provided as an added shielding feature and for the protection of the underside mounted components against damage due to careless handling. It is secured to the chassis with machine screws so that it is readily removable for repairs to effect replacement of chassis mounted components.

This receiver is especially designed to minimize radiation from the high-frequency oscillator. This is accomplished by isolating the antenna input circuits from the first detector and the high-frequency oscillator circuits through the use of extensive shielding and covering and by the use of a type of construction which reduces to practical limits undesirable circuit couplings by virtue of circulating currents and common shields.

A separate shielding compartment designed as a complete sub-assembly contains all the circuit elements between the antenna input and the signal grid of the r-f amplifier tube. This assembly is mounted at the rear center of the chassis. It is centrally disposed above and below the chassis through an aperture in the chassis.

A second shield compartment constructed and mounted in the same manner as that containing the antenna circuit outlet, but larger in over-all dimensions contains all of the circuit elements from the r-f amplifier tube to the first i-f amplifier input transformer, and includes also all circuit elements associated with the high-frequency oscillator. This compartment is mounted on the chassis between the front panel and the compartment containing the antenna input circuit elements.

Insulated mechanical couplings are employed for joining together the shafts of the tuning condensers and solid couplings employed for joining the bands of the selector shafts in the two shielding compartments. The r-f amplifier tube is mounted in a horizontal position in a socket which is provided with a clamp for securing the tube in place. The socket is mounted in one side wall of the large compartment and all wiring thereto is contained within the compartment. The vacuum tube then projects into the side of the compartment containing the antenna circuit components and connection to the single grid cap is made within the confines of the antenna compartment.

Removable cover plates secured with thumbscrews are provided on the two shielded compartments with access to the vacuum tubes contained within. Similar cover plates on the bottoms of the shielded compartments are secured with machine screws. For access to the circuit trimmer components, it is necessary to remove the top covers and on the bottom of the large units slide back the cover plate to expose the trimmers.

The secondary windings of the antenna coupling transformers feeding the grid of the r-f amplifier tube are provided with individual adjustable iron cores for inductance trimming. For capacitance trimming on bands 1, 2, and 3, a variable air trimmer, adjustable from the front panel, is provided. On bands 4 and 5, variable air trimmer condensers are provided and are accessible for adjustment after removing the bottom plate of the antenna unit. Access to the adjustable iron cores is provided upon removal of the top cover plate of the shielded compartment containing the antenna coupling transformers.

The r-f transformers coupling the plate of the r-f amplifier tube with the signal grid of the first detector are each provided with both inductance trimmers in the form of adjustable iron cores and condenser trimmers in the form of variable air condensers for purposes of alignment in these circuits with the high frequency oscillator circuits. Access to these trimmer components is afforded by sliding the bottom plate of the large unit containing the r-f and high-frequency oscillator components.

The high-frequency oscillator circuits are similarly provided with adjustable iron cores and adjustable air dielectric trimmer condensers for inductance and capacitance trimming. These adjustable trimmers, together with the padded condensers, permit the tracking of the high-frequency oscillator with the r-f amplifier circuit. The padder condensers on bands 3, 4, and 5 are of the fixed dielectric type. On bands 1 and 2, an adjustable air dielectric condenser is employed in parallel with the fixed mica dielectric condenser. All trimmer adjustments on the bottom of this unit are adjustable when the bottom plate is slid back to the open position. The trimmer adjustments on the top of the large unit are available when the top cover is removed.

4. *Circuit.* The actual schematic diagram of the model SLR–F radio receiver is shown in Figure 13–10. For purposes of illustration, it will be assumed that the circuits are set up as for reception on Band 1 as depicted in the diagram. The following description will refer, therefore, to the symbol numbers of the circuit elements of the band as, or when pertinent to, the description. It shall be assumed that, unless otherwise noted, the description will apply to all other bands equally.

5. *Signal Frequency Circuits.* Signal input to the receiver through antenna jack J–103 is connected to the primary winding of the antenna input transformer T–101 by switch S–101A. An electrostatic shield at ground potential separates the secondary winding from the primary winding on BANDS 2, 3, 4, and 5. The secondary winding of T–101 together with variable air dielectric capacitor C–158, and shunt connected capacitor C–156 constitutes the first tuned circuit. C–156 is a variable air dielectric condenser, and is controlled from the front panel by the knob marked ANT TRIMMER. This condenser is

connected in the circuit only on BANDS 1, 2, and 3. On BANDS 4 and 5, the circuits are aligned by adjustable air trimmers C–141 and C–142, which are located inside of the antenna shielded compartment. Transfer of r-f signal, at the resonant frequency of this tuned circuit, from the antenna to the control grid of r-f amplifier tube V–101, is accomplished by inductive coupling through antenna input transformer T–101. Variable condenser C–158 is ganged with variable condensers C–157A and C–157B to provide unicontrolled tuning of the receiver. The secondary winding of transformer T–101 is provided with adjustable iron core E–115 for inductance trimming and variable air dielectric condenser C–156 for capacitance trimming as stated above. These trimmer elements permit the accurate alignment of the tuned circuits at both ends of the frequency band. The high potential end of the tuned circuit is connected to the control grid of r-f amplifier tube V–101 by switch S–101B and through coupling condenser C–120. The low potential end of the tuned circuit is returned to ground. The d-c bias return from the control grid of r-f amplifier tube V–101 to the AVC bus is closed through grid resistor R–130. Inductor L–101 is connected in the primary circuit of the antenna transformer and is provided to attenuate signals of the i-f frequency. This inductor is tuned by condenser C–135 and is adjusted to resonance by adjustable iron core E–135.

Plate potential from the high-voltage d-c bus is applied to the plate of r-f amplifier tube V–101 through decoupling filter resistor R–115, by-passed to ground by condenser C–105B and condenser C–159. The suppressor is connected to the screen circuit which is operated at high potential. Initial bias is obtained by means of cathode resistor R–103 and SENSITIVITY control potentiometer R–140B, the cathode is by-passed by C–105A. Screen potential, also obtained from the high-voltage d-c bus, is applied to the screen through a decoupling filter consisting of filter resistor R–119 and by-pass condenser C–105C.

The amplified signal voltage from the plate of r-f amplifier tube V–101 is applied to the primary winding of r-f transformer T–106, and by inductive coupling is transferred to the control grid of first detector tube V–103 through the secondary winding of r-f transformer T–106, switch section S–101C, and coupling condenser C–121. The secondary winding of transformer T–106, together with variable air dielectric tuning condenser C–157B constitute the second and final tuned circuit operating at the signal frequency. The low potential end of the secondary winding of transformer T–106 connects to ground. Adjustable iron core E–119 and parallel-connected variable air dielectric condensers C–143 are provided for alignment purposes and are accessible for adjustment. The d-c bias return from the control grid of first detector tube V–103 to the AVC bus is closed through grid resistor R–131.

Screen potential from the high-voltage d-c bus is applied to the screen of first detector tube V–103 through r-f inductor L–102 by-passed to ground by C–106C and through decoupling filter resistor R–113 by-passed to ground by C–106B. The suppressor is internally connected to the shell of the tube. Initial bias is obtained by means of cathode resistor R–102, by-passed to ground by C–106A.

6. *High-frequency Oscillator Circuits.* The high-frequency oscillator is of the so-called "electron coupled" type. The tuned circuit consists of tapped inductor T–111 shunted with variable air dielectric trimmer condenser C–144 and tuned with variable, air dielectric tuning condenser C–157A, fixed padder condenser C–127, and variable, air dielectric padding condenser C–145. The inductor element is also provided with adjustable, iron core E–123 for inductance trimming. Padder condenser C–127 and C–145 is used to modify the tuning of the H. F. oscillator so that it will maintain a fixed frequency difference of 585 kc with respect to the signal frequency when tuning condensers C–158, C–157A, and C–157B are varied from minimum to maximum capacitance. Inductor T–111 is compensated for variations in temperature by condenser C–138 which has a negative temperature coefficient. The high potential end of the oscillator tuned circuit is connected, by switch S–101D, through coupling condenser C–136 to the control grid of the high-frequency oscillator tube V–102. This grid is returned to ground through grid resistor R–116 for d-c bias return. The low potential end of the tuned circuit is also returned to ground. The cathode of high-frequency oscillator tube V–102 is connected, by switch S–101D, to the tap on inductor T–111, and through coupling condenser C–137 to the oscillator injector grid of first detector tube V–103. This grid has a d-c return to ground through grid resistor R–114.

The plate of high-frequency oscillator tube V–102 is connected to the high-voltage d-c bus through decoupling filter resistor R–112, by-passed to ground by C–107B, and r-f filter inductor L–103, by-passed to ground by C–107C. One side of the heater circuit operates at ground potential while the other side is filtered by C–107A and r-f filter inductor L–104.

7. *I-f Amplifier Circuits.* The signal frequency arriving at the control grid of first detector tube V–103 and the high-frequency oscillator frequency arriving at the injector grid of this tube are mixed (or heterodyned) and the resultant difference frequency (585 kc) is fed to the input of the intermediate-frequency amplifier.

Transfer of intermediate-frequency energy, from the first detector tube V–103 to second detector tube V–107, is accomplished by inductive coupling through i-f transformers T–116, T–117, and T–118, and amplifier through i-f amplifier tubes V–104 and V–105. First i-f transformer T–116 consists of two tuned circuits, the primary and secondary wind-

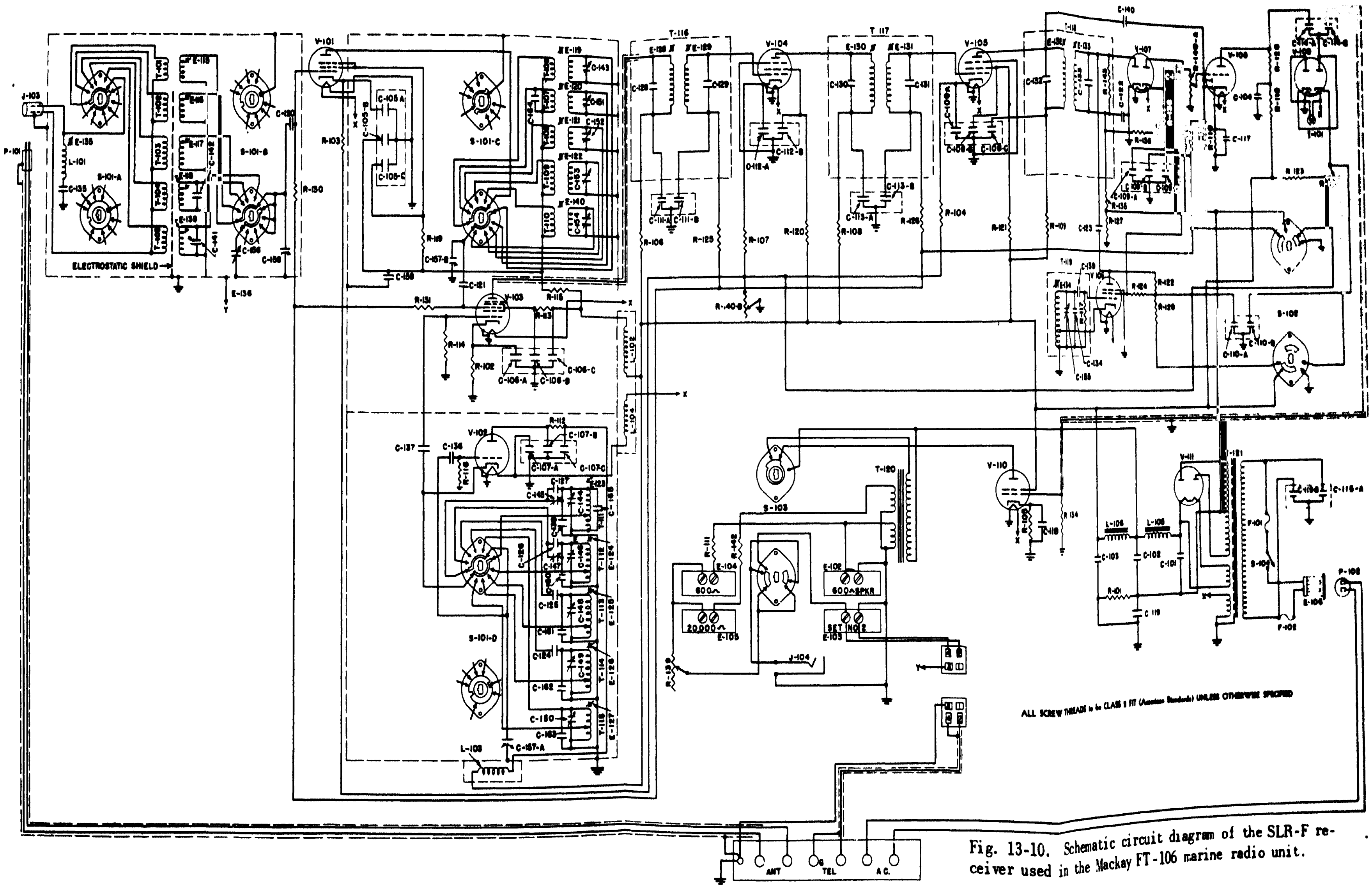


Fig. 13-10. Schematic circuit diagram of the SLR-F receiver used in the Mackay FT-106 marine radio unit.

ings are tuned to the intermediate frequency of 585 kc, by fixed condensers C–128 and C–129 and by adjustable iron cores E–128 and E–129, provided for inductance trimming and accessible through the top and bottom of the transformer shield can. The high potential end of the primary tuned circuit connects to the plate of first detector tube V–103 through a shielded conductor, while the low potential end of the winding connects to the high-voltage d-c bus through decoupling resistor R–106, by-passed to ground by C–111A. The high potential end of the secondary tuned circuit is connected to the grid of first i-f amplifier tube V–104 while the low potential end is connected to the AVC bus through AVC filter R–125 and C–111B.

Screen potential from the high-voltage d-c bus is applied to the screen of first i-f amplifier tube V–104 through decoupling filter resistor R–120, by-passed to ground by C–112B. Minimum bias is obtained through R–107, by-passed by C–112A.

Second i-f transformer T–117 is identical to first i-f transformer T–116, with respect to its design and construction. Accordingly, except for differences in circuit symbol designations which become obvious upon examination of the schematic diagram, the circuit description is applicable to this transformer, in all details.

The circuit arrangement of second i-f amplifier tube V–105 is the same, except for symbol designations, as described for first i-f amplifier tube V–104.

Third i-f transformer T–118 is identical in design and construction to second i-f transformer T–117, except for the coupling between the primary and secondary windings. Accordingly, except for differences in circuit symbol designations, the circuit description above is applicable to this transformer.

8. *Second Detector Circuits.* Tube V–107 is a dual diode tube. One section is used as the second detector, the plate of which is connected to the high potential end of the secondary winding of transformer T–118. The cathode is grounded, thus the tube acts as a half-wave rectifier. The other section of dual diode tube V–107 is used in a peak noise limiter circuit; a variable potentiometer R–138 is provided to adjust the threshold level at which the noise limiter will work. This control has a screwdriver slot in the shaft and is accessible through an opening in the right side of the receiver cabinet.

9. *CW Oscillator Circuits.* Associated with the second detector circuits is the CW oscillator tube V–106. The CW oscillator circuit normally operates at the i-f value of 585 kc. It provides an r-f potential with which an unmodulated i-f signal at the second detector can heterodyne to produce an audible CW beat note. The frequency of the CW oscillator circuit is determined by inductor T–119, parallel-connected C–134 and adjustable iron core E–134; condenser C–134 is a temperature compensating type and is used to keep the CW oscillator circuit stable when the temperature varies. This condenser has a positive temperature coefficient. The circuit of the CW oscillator is of the electron-coupled type. A variable air dielectric condenser, C–155, is connected across inductor T–119 and is controlled from the front panel of the receiver by knob E–111. This condenser is used to vary the frequency of the CW oscillator within narrow limits. Potential from the CW oscillator tube V–106 is coupled by means of C–123 to the detector diode plate of tube V–107. Plate potential is applied to the plate of CW oscillator tube V–106 through R–122 and filter resistor R–129, by-passed to ground by C–110A. Screen potential is applied to this tube through filter resistor R–124, by-passed by C–109A.

10. *Automatic Volume Control Circuits.* Automatic volume control is provided by the diode section of tube V–108. I-f potential from the plate of second i-f amplifier tube V–105 is applied to the diode plates of V–108 through C–140. This r-f potential is rectified by the diode and the voltage appearing across load resistor R–132 is filtered by R–133 and C–109B, and the resulting d-c voltage is used to control the gain of amplifier tubes V–101, V–103, V–104, and V–105, the degree of control being dependent on the strength of the incoming signal. This AVC voltage is applied to the tubes only when the RECEPTION switch on the front panel is set in the MOD position. Delay voltage is applied to the AVC bus by applying a negative 3-volt potential to the low potential end of R–132. This delay voltage is applied to the AVC bus so that the AVC will not become effective until a signal strong enough to develop approximately 3 volts across the diode load R–132 is applied to the plates of the diode section of tube V–108.

11. *Audio Amplifier Circuits.* The audio voltage developed across the diode load resistor R–127 as the result of the demodulating action of the second detector tube V–107 is applied to the control grid of first a-f amplifier tube V–108, through coupling condenser C–116 and VOLUME control potentiometer R–140A.

Amplification of the a-f signals from the second detector is accomplished by resistance-capacitance coupling between the first a-f amplifier tube V–108 and the second a-f output amplifier tube V–110. Dual diode tube V–109 is provided as an audio output limiter tube, and is connected in the audio circuit between V–108 and V–110. It is effective only when the RECEPTION switch on the front panel is in the CWOL position. Since the AVC system of the receiver is not functioning when in the CWOL reception position, a CW signal which is fading considerably will give a great variation in audio output. This tube is used to level off the peaks of fading signals so that a more constant audio output is provided at the phone jack or speaker terminals. A variable potentiometer R–137 is provided to adjust the level at which the output limiter circuit will work. This control is of the screwdriver type and is accessible for adjustment through an aperture in the left side of the receiver cabinet.

Transfer of audio-frequency energy, from the plate of output amplifier tube V-110 to head telephone jack J-104 and speaker terminals E-102, is accomplished through output transformer T-120. This transformer has two secondary windings, one of 600 ohms impedance, and the other of 20,000 ohms impedance.

12. *Reception Switch Circuits.* The RECEPTION switch S-102, mounted on the front panel of the receiver, provides the following circuit conditions:

MOD position: The r-f gain control R-140B is shorted out so that the r-f gain is maximum at all times the AVC circuit is operating. Potential from the high-voltage d-c bus is removed from the CW oscillator tube V-106 so that this circuit is not operating. Maximum bias is applied to the cathode of output limiter tube V-109 through R-123 and variable potentiometer R-137 from the high-voltage d-c bus so that this circuit does not operate.

CW position: The r-f gain control R-140B is connected in the circuit and controls the bias on V-101, V-104, and V-105, thus controlling the gain of these tubes. The AVC is shorted out so that it does not operate, and minus 3 volts is applied directly to the AVC bus. Potential from the high-voltage d-c bus is applied to the cw oscillator tube V-106 so that this circuit operates. The output limiter tube V-109 does not operate.

CWOL position: The r-f gain control R-140B, AVC circuit, and CW oscillator circuit are connected as explained above. Variable potentiometer R-137 in the output limiter circuit is grounded at one end and the bias on the cathode of V-109 can be adjusted so that the output level can be set to suit the operator.

13. *Phone Control Circuits.* The phone control switch S-103, mounted on the front panel of the receiver, provides the following circuit conditions:

Position NO. 1 provides for connecting the phone jack J-104 to the output transformer of the SLR-F through variable resistor R-139, terminal boards E-104, E-105, and resistors R-111 and R-142. Terminal E-104, marked 600 ohms and terminal E-105, marked 20,000 ohms, are provided so that the phone jack can be matched to transformer T-120 to use either 600-ohm or 20,000-ohm headphones. The shorting link should be placed across the proper terminal board to match the headphones being used. Resistors R-111 and R-142 are used to cut the audio output available at the headphone jack to approximately 100 milliwatts. The output can be adjusted from 100 milliwatts to approximately 1 milliwatt, by means of variable resistor R-139, which is of the screwdriver adjusting type, and is mounted on the left side of the receiver chassis.

The MIXED position provides for connecting the phone jack J-104 to the audio circuit as outlined in the paragraph above and, in addition, it also connects the phone jack to terminal board E-103 mounted in the rear of the receiver chassis. This terminal board is connected to the time check switch of the Marine Radio Unit. This switch must be in the MIXED position whenever the time check signals are being run from the SLR-F receiver to the jack provided near the chronometer.

Position NO. 2 provides for connecting the phone jack J-104 to terminal board E-103 only. This position will not normally be used, since there is no ready means of providing an input signal at the terminal board E-103.

14. *Rectifier Power Circuits.* The proper a-c heater potential for all vacuum tubes, except the rectifier, is obtained from one secondary winding of power transformer T-121. One side of this secondary is operated at ground potential. Filament potential for the rectifier is obtained from a second winding of this transformer. High-voltage a-c plate potential from a third winding of transformer T-121 is applied to the plates of rectifier tube V-111. The rectified pulsating potential is obtained from the filament of this tube and fed through a two-section filter consisting of L-105, L-106, and C-101, C-102, C-103, and thence to the high-voltage d-c bus. The center tap of high-voltage winding is returned to ground through R-101 which provides a negative 3 volts utilized for delay bias on the AVC bus.

The a-c power input line to the primary winding of power transformer T-121 is filtered by C-115A and C-115B to prevent stray r-f potentials from being applied across the primary winding. The primary winding is fused by F-101 and F-102 which should never be replaced with fuses of larger rating than 2 amp.

15. *Operating Instructions.* All switches and controls (with the exception of the main tuning control) of the SLR-F receiver are identified by panel engraving.

The main tuning control knob E-114 is located at the right side of the dial escutcheon in the center of the panel, and is secured to a shaft which drives the ganged main tuning condensers through a 25:1 ratio gear train. The dial calibration scale, N-105, is secured to a shaft and driven by the same gear train so as to give 338° rotation of the dial scale for 180° rotation of the tuning condensers. The dial calibration scale is directly calibrated in kilocycles on bands 1 and 2, and in megacycles on bands 3, 4, and 5. There is also a logging scale on the outer circumference of the dial scale marked 0 to 1000. The dial escutcheon E-137 is fitted with a transparent shatterproof lens on which the five frequency bands are designated by engraved numbers. Indirect dial illumination is afforded by dial lamp I-101 mounted in back of the dial scale.

The gain control R-140 is located at the left bottom end of the panel, and consists of two controls ganged together. The outside section R-140B controls the gain of the r-f amplifier tube V-101, and the first and second i-f amplifier tubes V-104 and V-105, when the RECEPTION control is in the CW or CWOL positions. The inside section of the gain control R-140A is used to control the input signal to the audio amplifier. This control is operated by knob E-108.

The ANTENNA TRIMMER control knob E-109 is located to the right of the GAIN control. This control is a variable air dielectric trimmer condenser connected across the antenna section of the main tuning condenser C-158. This control is used to compensate for variations in tracking which may be encountered when using different types of antennas. The control knob should be set at zero when tuning and adjusted for maximum gain when the desired signal is tuned in. This control is effective only on bands 1, 2, and 3.

The PHONE JACK J-104 is located in the center of the panel to the right of the ANTENNA TRIMMER control. This jack is connected to the PHONE CONTROL switch operated by knob E-113, located in the upper left-hand side of the panel. This control has three positions marked NO. 1, MIXED, NO. 2. In NO. 1 position, the output of the SLR-F receiver is connected to the PHONE JACK. In MIXED position, the output of the SLR-F receiver is attached to terminals E-103 in the rear of the receiver chassis marked SET NO. 2.

The BAND SELECTOR switch control knob E-110 is located to the right of the PHONE JACK. This control operates to select the r-f and high-frequency oscillator circuits for the five frequency bands covered by the receiver. The settings of this switch are marked 1, 2, 3, 4, and 5, and they coincide with the markings on the dial escutcheon.

The CW OSCILLATOR control knob E-111 is located to the right of the BAND SELECTOR control. The CW OSCILLATOR control is effective only when the RECEPTION control is in the CW or CWOL positions. This control varies the frequency of the cw oscillator which tunes to the intermediate frequency, 585 kc when the knob is set to zero.

The RECEPTION control knob E-112 is located above the CW OSC control. This control has three positions marked MOD, CW, and CWOL. In the MOD position, the cw osc circuit is off, the output limiter circuit is off, the sensitivity section of the GAIN control R-140B is shorted out, making the r-f gain of the receiver maximum. The AVC circuit is operating and the receiver is in the correct operating position for the reception of modulated signals. When the RECEPTION control is set to the CW position, the cw osc circuit is operating, the output limiter is off, the sensitivity section of GAIN control R-140B is switched into the circuit so that the r-f gain of the receiver can be controlled. The AVC circuit is shorted out and the receiver is adjusted for reception of cw signals. When the RECEPTION control is set to the CWOL position, all circuits are adjusted as in the cw position, with the exception of the OUTPUT LIMITER circuit, which is now switched into the circuit and, by adjusting the output limiter control R-137, the output level of the receiver can be adjusted so that on fading signals, the peaks are leveled off, keeping the audio output signal at a definite level.

The POWER switch S-104 is located in the center of the panel to the left of the dial escutcheon. The POWER switch is connected in the primary circuit of the power supply transformer of the receiver and receptacle E-106 is used.

Directly above the main tuning control is the DIAL LOCK control. When this control is turned clockwise, it locks the main tuning control so that it cannot be jarred out of position from vibration. The DIAL LOCK is released by turning the knob counterclockwise as far as necessary to allow the dial to turn freely.

A screwdriver type control R-139 marked PHONE OUTPUT ADJUSTMENT is located on the left side of the chassis. This control can be adjusted to raise or lower the audio output at the PHONE JACK from 1 milliwatt to 100 milliwatts, with a 600-ohm permanent magnet type speaker connected across the speaker terminal strip E-102.

A screwdriver type control R-138 marked NOISE LIMITER ADJUSTMENT is located on the right-hand side of the receiver chassis. This control is provided to adjust the threshold level of the noise limiter circuit to the noise conditions aboard ship.

Terminal strips E-104 and E-105 located on the left hand side of the Receiver chassis are provided to select the proper impedance match for either 600-ohm or 20,000-ohm head telephones. If 600-ohm phones are to be used, the shorting clip should be placed across the 600-ohm terminal strip E-104. If 20,000-ohm phones are to be used, the shorting clip should be placed across the 20,000-ohm terminal strip E-105.

A set screw wrench for hollow head set screws is furnished with each receiver. It is retained under two clips on the front of the oscillator-converter unit. This wrench can be used for removing all the control knobs also for loosening the set screws holding the r-f amplifier tube V-101. If this tube is removed for servicing or replacement, make certain that the three set screws holding the tube in place are tightened securely after replacing the tube in the socket.

Hand grips are provided on the front panel to aid in removing the chassis from the cabinet without subjecting the operating controls to any undue strain.

Never replace the line fuses F-101 and F-102 with any fuse of higher rating than 2 amps.

13–1h. Mackay Antenna Transfer Switch 107A and Grounding Switch of FT–106 Marine Radio Unit—The 107A antenna transfer switch is mounted at the upper left corner of the right-hand section of the Marine Unit, where it is wired directly to the feeders from the main, emergency, and auxiliary antennas. The switch is entirely back-panel connected with the handle protruding on the front. It is thereby made safe to handle under any condition.

The antenna grounding switch is located immediately below the 107A antenna transfer switch and is likewise entirely connected behind the panel with the handle grounded for protection of the operator.

1. With the 107A antenna switch in the IF MAIN-HF EMERGENCY position, and the antenna grounding switch pushed in, the antenna switch performs the following functions: The i-f transmitter is connected to the ship's main antenna. The high-frequency transmitter is connected to the ship's emergency antenna. The 128AV receiver operates on the main antenna through the break-in relay of the 155AY transmitter. The auxiliary antenna circuit is open, and the auto alarm antenna circuit is grounded. The auto alarm power circuits are open.

2. With the 107A antenna transfer switch in the HF MAIN-IF EMERGENCY position and the antenna grounding switch pushed in, the switches perform the following functions: The high-frequency transmitter is connected to the main antenna. The i-f transmitter is connected to the emergency antenna. The auxiliary antenna remains open. The auto alarm antenna circuit is grounded and the auto alarm power circuits are open. The 128AV receiver operates from the emergency antenna through the break-in relay of the 155AY transmitter.

3. With the 107A antenna transfer switch in the DF-AA position and the antenna grounding switch pushed in, circuits are completed as follows: The main antenna is connected to the auto alarm antenna circuit, from which the ground has been removed. The emergency antenna remains connected to the i-f transmitter. The circuit from the back contacts of the keying relay to the 128AV receiver has been opened and the 128AV receiver operates from the auxiliary antenna. The keying circuit of the transmitter has been opened, making it impossible to operate the transmitter with the switch in this position. The power circuits of the auto alarm have been closed, placing the auto alarm in operation. The direction finder interlock circuit has been closed as described in paragraph 5 below.

4. With the antenna grounding switch pulled out, the circuits are completed as follows: The circuit from the intermediate frequency transmitter to the artificial antenna is completed by the bottom contact of the antenna grounding switch. This permits testing the i-f transmitter with the artificial load. The i-f transmitter and high-frequency transmitter terminals of the 107A antenna transfer switch have been grounded, and both the main and emergency antennas are grounded when the 107A antenna transfer switch is in either the IF MAIN-HF EMERGENCY position or HF MAIN-IF EMERGENCY positions. If the 107A antenna transfer switch has been turned to the DF-AA position, the ground on the main antenna is opened, and the auto alarm is operative. The emergency antenna remains grounded.

5. A signal circuit and interlock circuit for the radio direction finder have been included in the 107A antenna transfer switch and the grounding switch. These function as follows: A red, warning light located above the switch handle of the 107A antenna transfer switch when lighted indicates that the direction finder has been turned on and that its use is desired. The direction finder cannot be placed in service until the antenna transfer switch is placed in the DF-AA position and the antenna grounding switch has been pushed in, that is, to the operating position. When both switches have been turned to their proper positions for operation of the direction finder, the circuit is completed through the auxiliary contacts upon the 107A antenna transfer switch and a push-button switch on the grounding switch to the power relay of the radio direction finder. The lamp remains lighted until the direction finder has been turned off.

13–1i. Battery Charging and Control Circuits of FT–106 Marine Radio Unit—1. Above the receivers on the right-hand section of the Marine Radio Unit are two etched panels and a voltmeter. On the etched panels are placed all the equipment necessary to control the charging and discharging of the auto alarm and receiver batteries, the auto alarm power supply control switch and pilot lamp, and the auto alarm signal lamp.

2. On the left end of the etched strips, is a toggle switch labeled CHARGER CONTROL CIRCUIT. The purpose of this switch is to remove entirely power from the charger circuits and resistors in case it is desired to replace resistors or to assure that none of the batteries controlled by the associated switches is inadvertently left on charge.

3. Next to this switch is a red pilot lamp marked AUTO ALARM. This light, which is in parallel with the alarm light on the bridge, gives a visual indication of misadjustment of the auto alarm. The function of this signal and the corrective measures to be pursued in case the alarm operates are described in detail in section 13–1d, paragraphs 17a and 17b.

4. The third toggle switch labeled RECEIVER CHARGER connects the charger circuit for the receiver batteries to whichever 6-volt receiver battery is to be charged, as determined by its associated switch marked RECEIVER BATTERIES. The RECEIVER CHARGER switch is essential, as it is not necessary to charge continuously one battery while the other is in use.

5. The switch labeled RECEIVER BATTERIES selects the receiver battery which is to be used, and the one which is to be charged. It is so arranged that when thrown to the left, receiver battery 2 is connected to the receiver, and battery 1 is placed in the charging circuit. When the switch is thrown to the right, the opposite occurs, battery 2 being connected to the charger and battery 1 being connected to the receiver. When thrown to OFF position, the battery circuits are opened. Whether or not the associated battery is actually charged when the RECEIVER BATTERY switch is placed in a position marked CHG. 1 or CHG. 2 depends upon whether or not the RECEIVER CHARGER switch is thrown. If placed in ON position, this toggle switch causes the battery to be charged at approximately 4 amps, and the ventilating fan to rotate slowly. The resistors for this charger circuit are placed on the lower rack behind the auto alarm cabinet and are labeled 9 OHMS.

6. In the center of the two etched plates is a d-c voltmeter, marked LINE VOLTAGE. This instrument provides a constant check of the voltage of the ship's supply line. It connects to the main line switch through the 1-amp fuses F–1, in the base of the right-hand section of the Marine Unit.

7. To the right of the line voltmeter is the AUTO ALARM BATTERIES switch. This switch controls the charging and discharging of the two sets of 24-volt batteries used for operating the auto alarm. When this switch is thrown to the left, battery 1 is placed in the charging circuit, and battery 2 is used to operate the auto alarm equipment. When thrown to the right, battery 2 is placed in the charging circuit, and battery 1 is connected to the auto alarm.

8. AUTO ALARM CHARGER switch connects power to the charging circuit, resulting in charging whichever battery has been selected for charging (as described above in paragraph 7). The charging rate is approximately 2 amp. The charging resistors are mounted on the lower rack behind the auto alarm cabinet and are labeled 15 OHMS. The ventilating fan is rotated at low speed by the operation of both the AUTO ALARM BATTERIES and the AUTO ALARM CHARGER switches.

9. The AUTO ALARM POWER light operates whenever the auto alarm power supply is functioning. It indicates that the auto alarm power supply has been turned on, and that the ship's line is being used to power the auto alarm equipment.

10. The switch marked AUTO ALARM POWER SUPPLY is used to turn on that unit. It should be thrown ON whenever the auto alarm is placed in operation, thus conserving the auxiliary dry B batteries. Throwing this switch to ON position lights the associated pilot lamp (AUTO ALARM POWER).

13–1j. Lights and Miscellaneous Equipment of FT-106 Marine Radio Unit—1. The Marine Radio Unit is provided with emergency lighting of all controls, the emergency generator, terminal equipment, fuses and "B" batteries. A shaded lamp atop the junction of the right-hand and center sections illuminates the radio clock, all controls, and the operating position. A second light in the base of the right section illuminates the motor generator and the power equipment. Both of these lamps operate from the 24-volt battery and are in no way dependent upon the ship's power supply. A spare emergency lamp is placed adjacent to the emergency light on top of the unit where it is available at any time should the emergency light burn out. The emergency lights are separately fused by fuses F3 in the base of the right section of the Marine Radio Unit.

Note: The emergency light should not be used for illumination when ship's power is available and when it is found necessary to use them, they should be turned off immediately when not in use, thus conserving battery power. These lamps, which are labeled 24 VOLTS, should never be placed in the socket connecting to the ship's 115-volt supply as they may explode when turned on and may cause personal injury.

2. An operating light is provided atop the junction of the left-hand and center sections. This light, which operates from 115-volt ship's line, provides illumination of all controls and the operating table. This lamp is wired in such a way that it may be turned on whenever the main switch located in the base of the right-hand section of the Marine Radio Unit has been turned on. The operating light should be used whenever ship's power is available, rather than using the emergency light, thus conserving battery power for emergency use.

3. Provision has been made in the Marine Radio Unit for a circuit to charge the direction finder batteries. This consists of a fuse block mounted on the rear panel of the right-hand section of the Marine Radio Unit, adjacent to the a-c line fuses. The cable to the direction finder battery charger may be connected to these fuses, F8, which in turn are connected directly to the main line switch. This provides the power for battery charging, the polarity of which may be determined instantly by observing the line voltmeter on the right-hand section of the Marine Radio Unit.

4. A time check circuit has been included with the receivers of the Marine Radio Unit. This consists of leads from the 128AV receiver and the SLR–F receiver which are brought to a time check switch located to the right of the SLR–F receiver in the left-hand section of the Marine Radio Unit. With this switch in the IF position, a circuit is completed from the 128AV receiver to a terminal board at the base of the left hand section, from which point a cable may run to a jack box located near the chronometer. With the time check switch in the HF position, the circuit is completed from the SLR–F receiver to the jack box near the chro-

nometer. With the switch in the OFF position, neither receiver is connected to the jack box.

5. A typewriter well has been built into the operating shelf of the FT-106 Marine Radio Unit. This functions as follows: The typewriter well consists of a flat surface, one side of which is covered with linoleum to match the rest of the operating shelf. With the linoleum covered side up, the surface is flush with that of the operating shelf on each side of the typewriter well. The shelf may be held in this position by means of a captive screw on each side of the bracket which reinforces the typewriter well. If it is desired to use a typewriter, the two captive screws may be loosened and the well permitted to revolve on the bearings provided for that purpose. When the center section of the shelf has revolved until the linoleum covered surface is down, a typewriter well approximately 4½ inches deep is provided. The shelf may be held in this position by means of the same two captive screws which now engage with nuts in the moving bracket, located opposite those originally used.

13–1k. Fusing of FT–106 Circuits—All circuits of the FT–106 Marine Radio Unit have been adequately fused, to protect the equipment in the event of failure of some components. Each of the fuses put in the Marine Unit operates to protect some portion of the equipment as described below.

1. *Power Circuit Fuses.* Two 60-amp fuses, F7, are located in the 115-volt d-c supply line of the Marine Radio Unit. These fuses are mounted in the box housing the main line switch and will remove all power from the Marine Unit should the individual fusing on the separate components fail to isolate the trouble.

Two 60-amp fuses, F4, are placed in a fuse block immediately below the main line switch. This fuse protects the 24-volt emergency battery against severe overload and is inserted on the circuit between the battery and the emergency motor generator meter.

Fuses labeled F1, mounted above the main terminal in the base of the right section of the Marine Radio Unit, are 1-amp fuses to which are connected the line voltmeter and the auto alarm power supply. The current requirement of these two units is low and adequate protection is provided by the 1-amp fuse.

The second fuse block in this group, F2, contains 20-amp fuses placed in the following circuit:

Receiver and auto alarm chargers
Ventilating fan
Service outlet

The third set of fuses in the group, F3 are 6-amp fuses in the 24-volt emergency light circuits.

Two 10-amp fuses, F8, are mounted in a fuse block on the rear panel of the right-hand section of the Marine Radio Unit. To this fuse block, the cable to the direction finder battery charger is connected. These fuses are of adequate size to carry any load normally imposed by the direction finder battery charger and are chosen large enough so that difficulty within the charger will normally blow fuses within the charger itself. These fuses then function as protection in the event of short circuits in the cable to the battery charger.

Between the direction finder battery charger fuses and the direction finder interlock terminal board on the rear panel of the right-hand section of the Marine Unit are mounted two 3-amp fuses in the a-c line supply to the Marine Radio Unit. Both receivers, which are connected to this line, are separately fused. These fuses may be removed to remove all a-c power from the Marine Radio Unit components.

2. *Transmitter Circuit Fuses.* Two 20-amp fuses, F1, Figure 13–3, provide overload protection for the 720-cycle power supplied to the rectifier and modulator transformers of the 155AY transmitter. These fuses serve to protect the equipment regardless of whether the rectifier is used with the high-frequency or the intermediate-frequency transmitters.

The 115-volt d-c line supply to the 155AY transmitter is fused by two fuses, F2, mounted on the base of the transmitter. These are 20-amp fuses.

The emergency battery charging circuit is fused by two fuses, F3. These are 20-amp fuses mounted on the base of the 155AY transmitter.

A high-voltage fuse, F10, provides protection on the plate supply circuit to the 167AY transmitter. This is a 1-amp fuse which is mounted inside a box on the rear panel of the left-hand section of the Marine Radio Unit.

3. *Auto Alarm Fuses.* The fuses associated with the auto alarm are mounted on the back of the auto alarm selector cabinet where they are easily accessible by opening the selector door from the front.

F5, a 3-amp fuse, which is placed in the receiver supply circuit, is the top fuse of the two mounted on this block. This fuse will blow if trouble occurs in the filament, relay, motor, or any other circuit within the auto alarm equipment.

F6 is a 6-amp fuse in the alarm circuits. All three bells and both alarm signal lights are in series with this fuse and a ground on any alarm circuit will result in blowing the fuse.

4. *Receiver Fuses.* Fuses for the 128AV receiver are mounted on the rear panel of the compartment in which the receiver is mounted. They are accessible by removing the receiver from the compartment and consist of the following:

(a) A-c line fuses F1 and F2 (Figure 13–8). These are 1-amp fuses which will blow in the event of short circuits or other failures within the rectifier supplying the plate voltage from the a-c line.

(b) A 5-amp fuse, F3, is inserted in the filament circuit of the 128AV receiver. This will blow if a short occurs in the tube filament circuit, dial light circuit, or within a tube itself. The dial lights will not light if this fuse has blown.

(c) A ⅛-amp fuse, F4, is inserted in the "B" battery circuit and will blow if a short circuit occurs anywhere in the high voltage supply circuit for the receiver. This fuse will open whether the rectifier or the "B" batteries are being used for plate supply in the receiver.

Two 2-amp fuses mounted on the rear of the chassis of the SLR–F receiver provide protection in the event of any failure within that receiver. These fuses are accessible by removing the receiver from the compartment within which it is mounted.

13–1l. FT–106 Storage Batteries—The following battery equipment is supplied with each Marine Radio Unit:

(a) Four MLL–15 6-volt, 235-ampere-hour trays comprising one 24-volt battery for the emergency transmitter. The specific gravity of these trays, fully charged, is 1.285.

(b) Eight MR–7 6-volt, 50-ampere-hour trays comprising two 24-volt batteries for operating the auto alarm.

(c) Two MR–7 6-volt, 50-ampere-hour trays, both of which are used for receiver 128AV. All 50-ampere-hour batteries are 1.210 specific gravity.

Keep all parts of battery clean and dry. When necessary, wash all covers with a rag dampened with fresh water. Keep connections clean and tight. Prevent corrosion by applying a thin coating of vaseline to brass or copper surfaces before bolting. Keep all filling plugs tightly in place, except when adding water or reading gravity. Never add acid. Select and mark a cell called a pilot cell in each battery for hydrometer readings. Every six months, change the pilot cell to avoid lowering the gravity of one cell, due to possible loss of electrolyte in taking readings. Using all cells spreads possible loss over all cells, rather than have the loss taken by a single cell.

1. *Discharging Batteries.* The 24-volt battery should be placed on discharge using the transmitter unkeyed as a load once each six months, if possible, for six hours. This should be done in port, or during layup, on the possibility of requiring the apparatus to be fixed. A time allowance of at least twenty-four hours can be provided for charging. Otherwise, the equipment should be used only for daily tasks or as may be necessary when an emergency occurs.

Alternately use each of the auto alarm batteries to carry the 1.4-amp load for the sixteen-hour auto alarm watch period during which the specific gravity should drop about 65 points, that is, from 1.210 to 1.145.

2. *Charging Batteries.* The emergency batteries should be kept fully charged as is indicated by a hydrometer reading of 1.285. After a period of prolonged use, the battery should be charged at a full charge rate of 8 amps until the specific gravity rises to 1.285. Hereafter, it can be floated using the ½-amp trickler rate for a number of hours a day. It is suggested that the main battery be placed on trickle charge during the sixteen hours the auto alarm is in use.

The auto alarm charger is proportioned to the discharge rate, that is, whenever the auto alarm is in use, using one battery, the other should be on charge. This results in returning the unused battery to a fully charged condition, at the conclusion of a sixteen-hour period of auto alarm watch.

The receiver batteries should be charged approximately one hour for each two hours of use, or as is sufficient to return them to a fully charged state. They should never be overcharged.

Do not overcharge batteries. A rapid decrease in the water level of cells indicates overcharge.

Once a month after reading specific gravity of batteries coming off discharge, add distilled water or other approved water (never anything else) to all cells to bring the top of the electrolyte to ⅜ inches above the top of the separators. If water evaporation is too rapid, charging periods should be reduced.

Twice a year (every six months) charge each battery for a full twenty-four-hour period. Be sure to water all cells before starting this charge. Fifteen minutes after the end of the charge, read the specific gravity of all cells. Record these readings, as required by the operating company.

13–1m. FT–106 Part Replacements—In replacing parts in any of the apparatus, exact specifications on most parts may be determined by consulting the wiring diagram and/or parts lists. The part, if replaced from the spare parts box, should be replaced as soon as possible. If not included in the spares, the part should be ordered, using the information listed in the electrical parts list from the first available service point.

"B" batteries should be replaced whenever the voltage of the set of two batteries drops to 75 volts on load. The batteries are inserted from the front and may be connected and tested for voltage from the top through the door on the right side of the Marine Radio Unit.

The charging resistors may be replaced by removing the wires connecting to the defective resistor, removing one end bracket and sliding the resistor out of the other spring clip. In case one resistor goes open, it may be temporarily shorted out. This increases the charging rate, and the charging time for the particular battery should be decreased. The charging resistors are mounted behind the auto alarm cabinet as follows:

(a) The emergency battery chargers, R-7 to R-12 on RC-2922-14, are labeled 1.9 ohms and mounted on the top row of the resistor rack.

(b) The trickle charging resistor R-13 is 170 ohms and is located at the inside end of the top row of resistors.

(c) The receiver battery chargers are 9 ohms each, R-4 to R-6 on RC-2922-14, and are located on the lower resistor rack.

(d) The auto alarm battery charger resistors, R-1 to R-3, are located on the lower resistor rack. They are labeled 15 ohms.

13-1n. FT-106 Ventilating Fan Circuits—The ventilating fan is arranged to operate in series with a 60-ohm resistor across the line. A second 60-ohm resistor (R-17) may also be inserted in series with the fan. This provides a reduced speed for exhausting a low volume of heat, such as is radiated by the receiver battery chargers, the auto alarm battery chargers, or the emergency battery trickle charger.

(a) The fan rotates when the transmitter is operated on the ship's line. It will normally rotate at the slow rate of speed, unless the TRICKLE CHARGE-FULL CHARGE switch is thrown to FULL CHARGE. This increases the speed of the fan so as to exhaust the increased volume of heat. The normal position for the trickle charge switch, when the full charger is not being used, is in TRICKLE CHARGE position. The fan is operated, in this case, by a contact of the LINE switch.

(b) The fan operates also when the BATTERY switch on the transmitter is thrown to CHARGE position. Switch S-9 controls the speed of the fan by shorting out or inserting the 60-ohm series resistor in the fan circuit.

(c) The fan is operated by throwing the RECEIVER CHARGER and RECEIVER BATTERIES switches to an ON position. Both switches must be thrown. The fan will rotate slowly *unless* the TRICKLE CHARGE switch on transmitter 155AY is up. It should be kept in the lower position when not in use, but provides means for increasing the ventilation should the temperature warrant.

(d) The fan functions when the AUTO ALARM BATTERIES and AUTO ALARM CHARGERS switches are thrown so as to charge, in a similar manner to that described under (c). The speed of the fan is controllable by the toggle switch on transmitter 155AY but will normally be at low speed.

13-2. RMCA Model 4U Radio Unit—The Radiomarine Model 4U radio unit is a self-contained type of shipboard radio equipment, designed and manufactured for installation on U. S. Maritime Commission vessels. A basic consideration governing the design is provision for installation in a minimum of time. This is accomplished in model 4U by means of "unit frame" construction, wherein the various radio units are completely assembled and wired at the factory in their respective frames. Prefabricated "interframe" cables are supplied.

All external power wiring and auxiliary circuits are brought into the base sections of the model 4U. These circuits comprise the ship's 115-volt d-c main or emergency power supply, 6- and 12-volt storage battery circuits, and the external circuits required for the auto alarm, the direction finder, and the time signal circuits. On some vessels, a 115-volt, 60-cycle, single-phase, a-c supply is also brought in to the model 4U to furnish power for a type RM-23 rectifier unit.

A brief summary of model 4U major components is listed below. These components are described in greater detail further in this chapter. The assembly includes the following units:

1. Main transmitter, three tubes, 200 watts output, 8 frequencies, 350 to 500 kc, A1 and A2 emission, model ET-8024-A.
2. Emergency transmitter, six tubes, 40 watts output, 5 frequencies, 350 to 500 kc, A2 emission, model ET-8025.
3. High-frequency transmitter, five tubes, 200 watts output, 2000 to 24,000 kc, A1 and A2 emission, model ET-8023.
4. Main and emergency receiver, five tubes, low and intermediate frequency, 15 to 650 kc, model AR-8510.
5. Communication receiver, ten tubes, intermediate and high frequency, 85 to 550 kc, and 1900 to 25,000 kc, model AR-8506-B.
6. Emergency crystal receiver, intermediate frequency, 350 to 515 kc, type D.
7. Auto alarm, nine tubes, for automatic reception of the International Auto Alarm Signal on 500 kc, model AR-8601.
8. Alarm signal keyer, for automatic transmission of the International Auto Alarm Signal, model AR-8651.
9. Transmitter selector switch for quickly connecting the various transmitters to the antennas.
10. Motor generator transfer switch for quickly connecting the main motor generator to the ET-8024-A or ET-8023 transmitters.
11. Main motor generator operating from 115 volt d-c to furnish power to the ET-8023 or ET-8024-A transmitters.
12. Main motor generator automatic starter.
13. Type RM-8 line filter unit for AR-8506-B receiver.
14. Emergency motor generator operating from 12-volt storage battery for supplying power to ET-8025 emergency transmitter.
15. Rectifier unit type RM-23, operating from 115-volt, 60-cycle a.c. to furnish 90-volt d.c. for AR-8510 receiver plate supply. (This

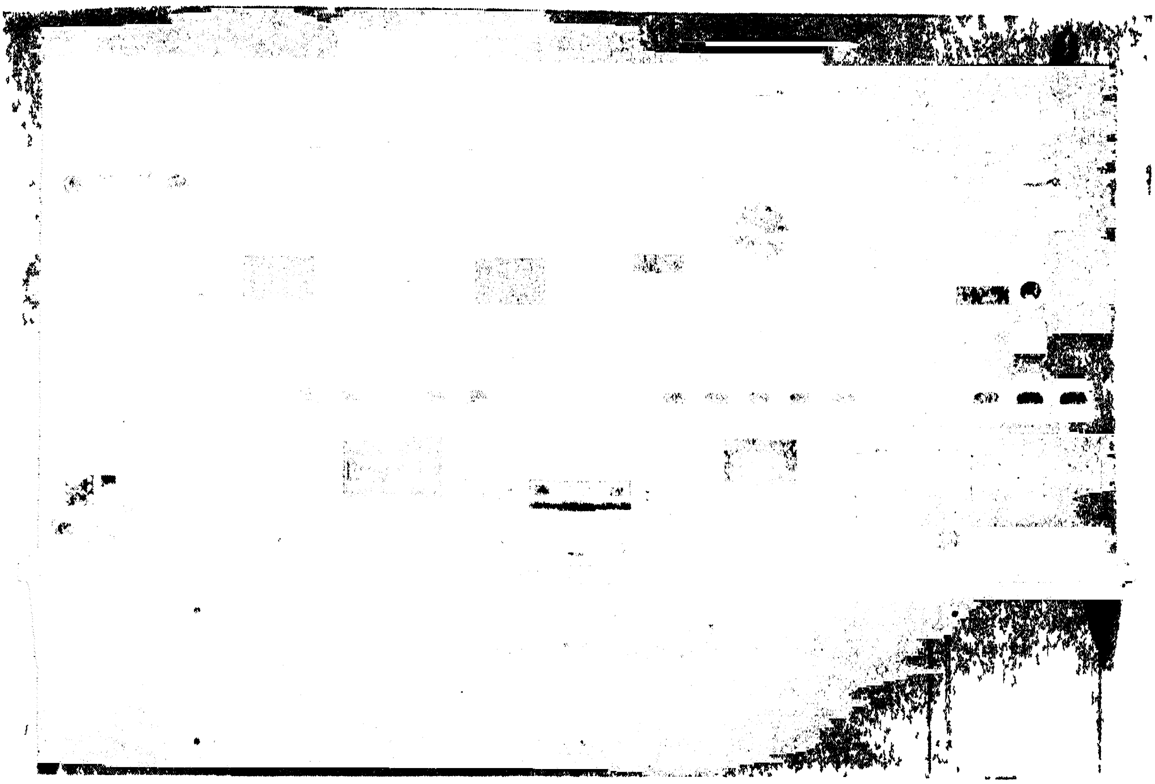


FIG 13-11 The RMCA model 4U marine radio unit

unit normally furnished only for Victory vessels)

16 The receiver power switch, for AR-8510 receiver, which permits selection of the 90-volt supply from the type RM-23 rectifier unit or from the 90-volt B batteries which are furnished.

17. 12-volt emergency light at top of frame B, for illuminating main and emergency transmitters and main and emergency receivers.

18. 115-volt console light at top of frame D for general illumination of the console.

19. Battery charging facilities with appropriate switching and charging resistors for the 12-volt emergency storage battery, the two 6-volt receiver A storage batteries and the auto alarm 6-volt storage battery.

20. Fuse panels for fusing the various circuits in the console unit.

21. 115-volt d c., 60-amp, double-pole single-throw, main line switch mounted in the lower section of frame C.

22. Operating table, 18 inches in depth running the entire length of the model 4U assembly.

23. Typewriter well 20 inches wide, 4½ inches deep, with clamps for securing typewriter. This typewriter well is hinged so that typewriter may be removed and the well reversed in order to provide a continuous flush working surface on the operating table.

24. Time signal cord and plug, which is wired to chart room, to enable the radio operator to connect this circuit to either the AR-8510 or AR-8506-B receiver.

25. Three telegraph keys. One of these keys is used with the ET-8025 emergency transmitter. The other two keys, connected in parallel, are used with the ET-8023 or ET-8024-A transmitters and are automatically switched by the motor generator transfer switch.

26. Message compartments are provided in frames B and C behind the operating table. A third compartment for stowage of telephone receivers or message forms is provided in frame A.

27. Transmitter "Seals" for ET-8023, ET-8024-A and ET-8025 are furnished.

13-2a. External Units for Model 4U—A type RM-10 artificial antenna unit is furnished with each model 4U for testing the ET-8025 emergency transmitter as required by F.C.C. Rules. This unit is normally stowed in the radio room and is provided with test leads and clips for conveniently connecting it to the antenna circuit of the emergency transmitter.

The following storage batteries are furnished for installation in the battery room.

- One 12-volt storage battery, type HS-17, for ET-8025 emergency transmitter, AR-8651 alarm signal keyer and emergency lights. This battery comprises two 6-volt units connected in series, 17 plates, capacity 44 amps for six hours, full charge gravity 1.285.
- Two 6-volt storage batteries for AR-8510 receiver, type 3-DLTL-9, 9 plates, capacity 2 amps for 35 hours, full charge gravity 1.220.
- One 6-volt storage battery for AR-8601 auto alarm, type 3-DLTL-9, 9 plates, capacity 2 amp for 35 hours, full charge gravity 1.220.

A type RM-25 auto alarm bell and warning light unit is furnished for installation on the bridge.

A type RM-26 auto alarm bell unit is furnished for installation in the radio operator's quarters.

A type RM-22 time signal jack box is furnished for installation in the chart room.

In frame C, the transmitter selector switch provides a "Direction Finder Position," and a direction finder signal light is mounted on the 12-volt battery control and charging panel in frame C. These facilities enable the user of the direction finder to signal the radio operator, the latter then placing the transmitter selector switch in the direction finder position which closes the interlock circuit, applying power to the direction finder. Under these conditions the auxiliary receiving antenna is automatically connected to the AR-8510 receiver or the type D crystal receiver. A 5-conductor L and A cable is required between the direction finder and the model 4U radio unit for the necessary interlock and direction finder battery charging circuits.

13-2b. 4U Power Supply—The basic power supply for the model 4U is 115 volts d.c. The total power consumption from this source, with all batteries on charge and with the key locked on the main transmitter, is approximately 3.6 kw. However, under normal operating conditions with the main transmitter being keyed and the 12-volt emergency battery on trickle charge, the 115-volt d-c power consumption is about 2.3 kw. Under conditions where the shipboard emergency 115-volt d-c supply would be used, the batteries ordinarily would not be on charge, which still further reduces the power consumption so that approximately 1.75 kw are required.

A supply of 115-volt, single-phase, 60-cycle power is also required. This supply is used to operate the type RM-23 rectifier unit for the AR-8510 receiver, requiring approximately 35 watts. For vessels where the 115-volt a-c source is not available to supply the type RM-23 rectifier, the AR-8510 receiver is then operated from its 90-volt B batteries for plate supply.

The utilization of the various sources of power for the model 4U may be summarized as follows:

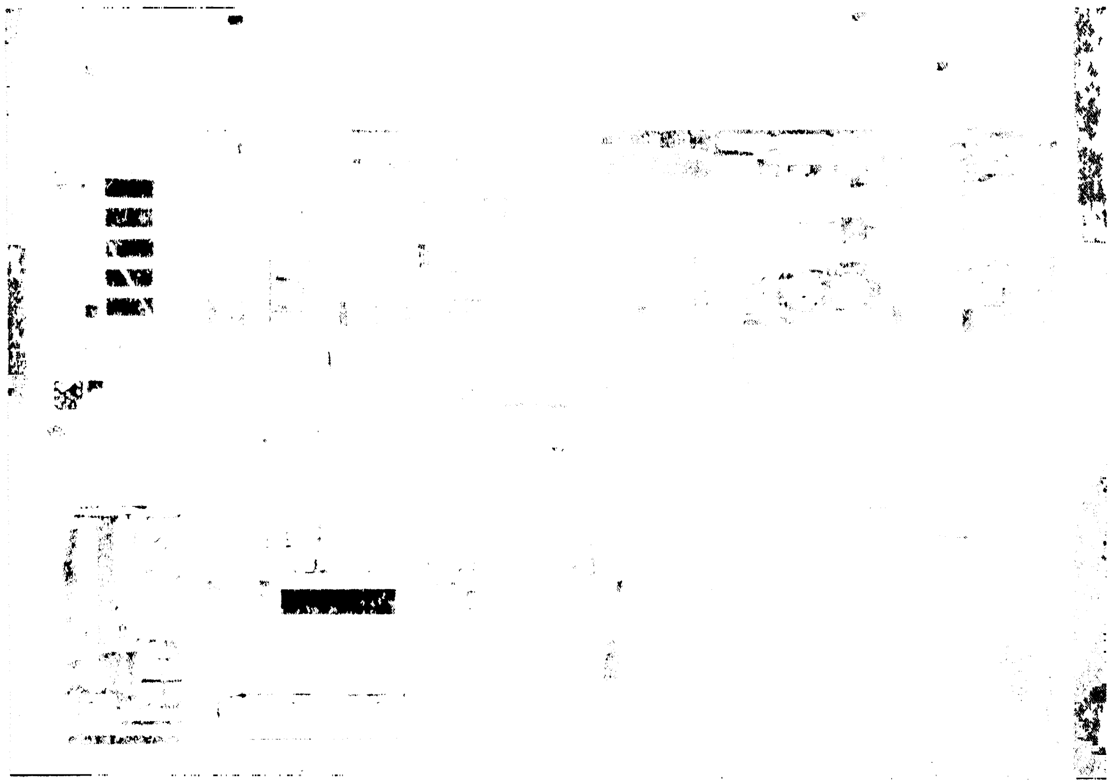


FIG. 13-12. The RMCA model 4-U marine radio unit showing interior view of equipment.

115-volt d.c.: This source operates the main motor generator used with the ET–8023 or ET–8024–A transmitter, the AR–8506–B receiver, all battery charging including the direction finder battery, the AR–8601 auto alarm and the 115-volt console light.

115-volt a.c.: This source operates the type RM–23 rectifier unit.

12-volt storage battery: This battery operates the ET–8025 emergency transmitter, the emergency light and the AR–8651 alarm signal keyer.

6-volt receiver storage batteries (2): These batteries operate the filament (heater) circuit of the AR–8510 receiver.

6-volt auto alarm storage battery: This battery operates the bells, lights, relays, etc., in the AR–8601 auto alarm.

13–2c. 4U Operation Instructions—Reference should be made to the detailed operating instructions, further in this chapter for the auto alarm, radio transmitters and radio receivers. The instructions given immediately below are a condensed summary to enable radio personnel to understand the general over-all operation of the model 4U.

The functions of the switches which select the antennas and which connect these antennas to the transmitters, receivers and auto alarm should be clearly understood. These switches are the AUTO ALARM MASTER SWITCH and TRANSMITTER SELECTOR SWITCH.

The AUTO ALARM MASTER SWITCH, located in the top of frame A, is a three-position switch.

Position 1 turns on the AR–8601 auto alarm and connects it to the main antenna.

Position 2 disconnects the auto alarm, takes the auto alarm battery off charge, and connects the emergency antenna to the TRANSMITTER SELECTOR SWITCH.

Position 3 disconnects the auto alarm, places the auto alarm 6-volt battery on charge, and connects the main antenna to the TRANSMITTER SELECTOR SWITCH.

In other words, positions 2 and 3 are transmitting positions, with position 3 normally in use when the radio operator is on duty. It should be noted, therefore, that positions 2 and 3 permit quick selection of either the emergency or the main antenna.

The TRANSMITTER SELECTOR SWITCH is a five-position unit, located in the upper section of frame C.

Position 1 connects the ET–8023 high-frequency transmitter to the emergency or main antenna (depending upon whether the AUTO ALARM MASTER SWITCH is in position 2 or 3).

Position 2 connects the emergency or main antenna to the ET–8024–A main transmitter. Also in position 2 the antenna is connected, through the break-in relay in the ET–8024–A transmitter, to the AR–8510 receiver.

Position 3 connects the emergency or main antenna to the ET–8025 emergency transmitter and also keeps the AR–8510 receiver connected to the antenna through the break-in relay in the ET–8025 transmitter.

Position 4 grounds the emergency or main antenna depending on position 2 or 3 of the AUTO ALARM MASTER SWITCH. Normally the main antenna should be grounded during severe lightning storms.

Position 5 is the direction finder position. In this position the emergency and main antennas are open-circuited to avoid impairment of the direction finder calibration. Also in this position the auxiliary receiving antenna is automatically connected to the AR–8510 receiver. In addition, position 5 closes the direction finder interlock circuit to enable power to be applied to the direction finder from the wheelhouse. Position 5 will normally be used when the radio operator is off duty so as to permit the wheelhouse to use the direction finder, or when the operator is on duty and the wheelhouse calls for the direction finder by means of the D.F. signal light in frame C below the ET–8025 transmitter.

Reference should be made to the Switching Chart, located on frames A and C, for a summary of the correct positions of the AUTO ALARM MASTER SWITCH and TRANSMITTER SELECTOR SWITCH.

A MOTOR GENERATOR TRANSFER SWITCH is located in frame D to the left of the high-frequency receiver. This switch transfers the circuits of the main motor generator unit so that this machine may supply power to the ET–8024–A main transmitter (right-hand position) or to the ET–8023 high-frequency transmitter (left-hand position). This switch should not be operated when the motor generator is running, as the machine should be started or stopped by means of the START-STOP SWITCH on the respective transmitters. The ET–8025 emergency transmitter has its own 12-volt battery-operated motor generator and is, therefore, independent of the main motor generator and the MOTOR GENERATOR TRANSFER SWITCH.

There are three telegraph keys. Two of these keys, located under the MOTOR GENERATOR TRANSFER SWITCH and the AR–8510 receiver, are connected in parallel so that either may be used with the ET–8023 or ET–8024–A transmitters. These keys are automatically switched to the desired transmitter by means of the motor generator transfer switch. The third key, located below the ET–8025 emergency transmitter is used to operate that set and is independent of the other two keys.

Transmitter SEALS are provided for the START-STOP SWITCHES on each of the three transmitters. SEALS are to be broken only when authorized, and the hinged plate then opened, permitting closure of the START-STOP SWITCHES.

A RECEIVER POWER SWITCH, located to the right of the AR–8510 receiver, is provided to control the input to that receiver. Normally the ON-OFF BATTERY toggle switch on the front panel of the receiver itself should be left ON. The three position RECEIVER POWER SWITCH should then be used to turn the receiver off, or to connect it to the 90-volt rectifier unit (RM–23), or to the 90-volt B battery. On vessels where the RM–23 is not furnished, a second 90-volt B battery (two 45-volt units) may be installed, if desired, and connected to the plus 90- and minus 90-volt leads which normally run to the rectifier unit. If this is done, the use of the two sets of 90-volt B batteries may be alternated to secure maximum life. In all cases, the receiver should be turned off with the three-position POWER SWITCH, as this will automatically disconnect the A battery supply and the input to the RM–23 rectifier when the latter is used.

The high-frequency radio receiver (AR–8506–B or SLR–F) uses its own doublet receiving antenna which is connected at all times to the receiver. This permits the high-frequency receiver to be used independently of all other antennas and without regard to the positions of the AUTO ALARM MASTER SWITCH or the TRANSMITTER SELECTOR SWITCH.

The MAIN LINE SAFETY SWITCH in the lower section of frame C should be kept closed at all times to apply the shipboard 115-volt d-c power supply for operation of the transmitters, auto alarm, battery charging, etc. Always open this switch when making repairs or replacing fuses in the equipment.

To test the ET–8025 emergency transmitter with the RM–10 artificial antenna unit, connect the red lead from the RM–10 to the stud on the forward insulator above the TRANSMITTER SELECTOR SWITCH. Connect the black lead from the RM–10 to the ground stud provided. Place the TRANSMITTER SELECTOR SWITCH in position 4 (antenna grounded). Be sure to disconnect and remove the RM–10 after testing.

To pass a time signal to the bridge, withdraw the plug in the top of the type D crystal receiver and connect this plug to one of the phone jacks on the AR–8510 or the high-frequency receiver, as required.

To use the 12-volt emergency light, place CHARGE-DISCHARGE SWITCH under ET–8025 transmitter in the DISCHARGE position. Then close 12-VOLT EMERGENCY LIGHT SWITCH located to the left of the AR-8510 receiver.

To charge or discharge the 12-volt emergency transmitter battery, the two 6-volt receiver A batteries, and the auto alarm 6-volt battery, refer to the detailed instructions covered in this chapter.

Adjustable retaining strips are provided in the typewriter well to prevent movement of the typewriter. These retaining strips should be moved forward or backward to properly conform to the base of the typewriter and then tightened in place with the screws provided. The typewriter well should *not* be inverted after typewriter has been installed.

A brief summary of "Operating Conditions" for the various transmitters, receivers, etc. is listed on the following pages.

13–2d. Condensed Operating Instructions

1. *Condition 1. To place main transmitter, ET–8024–A on air.*

(a) AUTO ALARM MASTER SWITCH: Position 2 (emergency antenna) or position 3 (main antenna).

(b) MOTOR GENERATOR TRANSFER SWITCH: Right-hand position (ET–8024–A).

(c) TRANSMITTER SELECTOR SWITCH: Position 2 (ET–8024–A).

(d) Start motor generator. Select frequency and emission, set filament voltage to 10, plate voltage to 1400, close key and resonate antenna.

2. *Condition 2. To place emergency transmitter, ET–8025, on air.*

(a) AUTO ALARM MASTER SWITCH: Position 2 (emergency antenna) or position 3 (main antenna).

(b) TRANSMITTER SELECTOR SWITCH: Position 3 (ET–8025).

(c) CHARGE-DISCHARGE SWITCH: 12-volt battery on DISCHARGE position.

(d) 12-VOLT EMERGENCY LIGHT SWITCH: ON position.

(e) EMERGENCY MOTOR GENERATOR STOP-START SWITCH: START position.

(f) Select frequency, set filament voltage to 10, close key and resonate antenna.

3. *Condition 3. To place high-frequency transmitter, ET–8023, on air.*

(a) AUTO ALARM MASTER SWITCH: Position 2 (emergency antenna) or position 3 (main antenna).

(b) MOTOR GENERATOR TRANSFER SWITCH: Left-hand position (ET–8023).

(c) TRANSMITTER SELECTOR SWITCH: Position 1 (ET–8023).

(d) Start motor generator, select emission, set filament voltage to 10, plate voltage to 1400. Refer to tuning chart on panel, set all controls and close tuning key to check loading into antenna.

4. *Condition 4. Main receiver, AR–8510, in operation.*

(a) AUTO ALARM MASTER SWITCH: Position 2 (emergency antenna) or position 3 (main antenna).

(b) TRANSMITTER SELECTOR SWITCH: Position 2 or 3 (depending whether ET–8024–A or ET–8025 transmitter is selected) or position 5 (D.F. position) which connects auxiliary antenna to AR–8510 receiver when direction finder is in use.

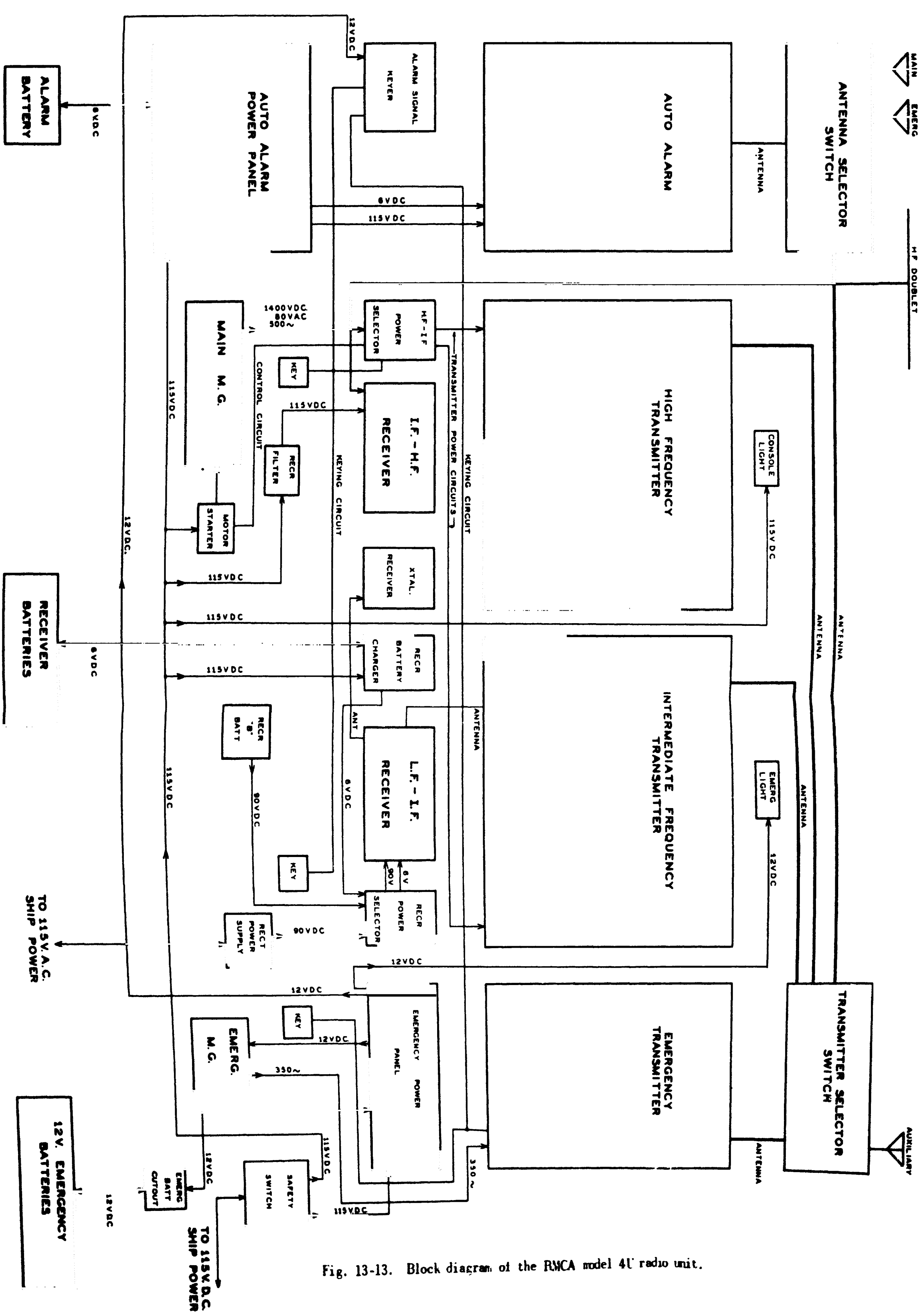


Fig. 13-13. Block diagram of the RMCA model 4U radio unit.

(c) 6-VOLT RECEIVER BATTERY DISCHARGE-CHARGE SWITCHES: Either one on DISCHARGE.

(d) AR–8510 RECEIVER POWER SWITCH: RECTIFIER position (if a-c supply is on) otherwise place in "B" BATTERY position.

(e) BATTERY SWITCH (on receiver panel): ON position.

(f) ANTENNA SWITCH (on receiver panel): MAIN position.

(g) Adjust band switch, r-f gain and regeneration, and tune signal.

5. *Condition 5. AR–8506–B receiver in operation.*

(a) Turn r-f gain control clockwise, thus applying power to receiver. Adjust band switch, a-f gain, AVC, BFO, and tune in desired signal. This receiver has its own doublet antenna and may be operated without regard to other switching on model 4U.

6. *Condition 6. To transmit auto alarm signal.*

(a) Adjust main (ET–8024–A) transmitter to 500 kc if ship's power is available. Otherwise adjust emergency (ET–8025) transmitter to 500 kc.

(b) Be sure 12-volt battery is on discharge, using CHARGE-DISCHARGE SWITCH on ET–8025 panel.

(c) Turn on AR–8651 alarm signal keyer and let it key transmitter for about 90 seconds. Turn keyer OFF, listen on receiver and repeat keyer operation if necessary. Follow instruction card on AR–8651.

7. *Condition 7. To place auto alarm on watch.*

(a) Place AUTO ALARM MASTER SWITCH in position 1.

(b) Follow instruction card on auto alarm.

8. *Condition 8. Miscellaneous operation.*

(a) Keep both 6-volt receiver batteries and the 12-volt emergency battery properly charged. Charge auto alarm 6-volt battery by placing MASTER SWITCH in position 3. To avoid overcharge of alarm battery, place MASTER SWITCH in position 2 which also permits AR–8510 receiver to be connected, through transmitter, to emergency antenna.

(b) When bridge requires direction finder, place TRANSMITTER SELECTOR SWITCH in position 5. AR–8510 receiver is then connected to auxiliary antenna.

(c) To ground antenna, place ALARM MASTER SWITCH in position 2 or 3, and TRANSMITTER SELECTOR SWITCH in position 4.

(d) To use emergency crystal receiver, place AR–8510 ANTENNA SWITCH to EMERGENCY, and AUTO ALARM MASTER SWITCH in position 2 or 3.

13–2e. RMCA Model ET–8023 High-frequency Radiotelegraph (Component of Model 4U Radio Unit)—The ET–8023 transmitter is designed to cover, by means of front panel adjustments, a continuous frequency range of 2000 to 24,000 kc (2–24 mc). This frequency range more than covers the requirements of the U. S. Maritime Commission of 2000 to 18,100 kc, without gaps, so as to provide an integrated service between the Merchant Fleet and the U. S. Navy.

The complete frequency range of 2000 to 24,000 kc is divided into nine bands as listed below. Suitable overlap is provided so that the lowest and highest frequencies listed in each band may also be obtained in the adjacent band.

Band	*Output Frequency*
1	2000– 2670
2	2670– 3560
3	3560– 4750
4	4750– 6340
5	6340– 8440
6	8440–11,270
7	11,270–15,000
8	15,000–20,000
9	20,000–24,000

In the ET–8023 transmitter, the oscillator circuit is designed to cover the frequency band of 1500 to 3000 kc. The fundamental, second, third, fourth, sixth, or eighth harmonic of the oscillator frequency is used to obtain the final output frequency. This circuit arrangement permits maximum economy in the number of crystals required for several output frequencies as described further under "Frequency Control."

1. *Antenna Power.* The transmitter is designed to deliver to a suitable antenna the power listed below:

Frequency Range (kc)	*Emission*	*Power (watts)*
2000–17,000	A-2	225
2000–17,000	A-1	180
17,000–18,100	A-2	200
17,000–18,100	A-1	160
18,100–24,000	A-2	180
18,100–24,000	A-1	150

2. *Type of Antenna.* The ET–8023 transmitter is designed to operate into the normal main antenna used aboard ship for intermediate frequencies. In other words, no special short-wave antenna is required. On vessels which are fitted with a separate emergency transmitting antenna with conventional antenna switching means for such antenna, the ET–8023 transmitter may also be operated into that antenna.

3. *Type of Emission.* The transmitter is designed to provide A1 (continuous wave) and A2 (modulated wave) emission. For A2 emission the modulation frequency is approximately 500 cycles and the modulation percentage not less than 70 percent nor more than 100 percent.

4. *Frequency Control.* The transmitter is designed so that it may be operated either as a master oscillator type of transmitter or as a crystal-controlled transmitter. A frequency tolerance of

0.02 percent with crystal control or 0.05 percent with master oscillator control is provided.

Provision is made for a maximum of ten type R1 quartz crystals. Only four crystals are required to provide one calling and one working frequency in each of the eight marine bands listed below (in kilocycles):

4140–4165	11,020–11,070
5510–5535	12,360–12,480
6210–6240	16,500–16,660
8240–8330	22,025–22,140

For example, the use of four crystals, 2070, 2080, 2760 and 2765 kc, will provide the following calling and working frequencies. Four such crystals are furnished with model 4U Radio Unit.

Crystal Frequency (kc)	Output Frequencies in Kilocycles				
	No. 1	No. 2	No. 3	No. 4	No. 5
2070 (c)	4140	6210	8280	12,420	16,560
2080 (w)	4160	6240	8320	12,480	16,640
2760 (c)	5520	11,040	16,560	22,080	—
2765 (w)	5530	11,060	16,590	22,120	—

Note: (c) represents calling frquency.
(w) represents working frequency.

The above list shows how the four crystals will provide eight calling and nine working frequencies, totaling seventeen frequencies in the eight standard marine bands. It will be noted that the calling frequency of 16,560 kc is obtained either with the 2070 or 2760 crystal.

5. *Vacuum Tubes.* The transmitter uses a total of five vacuum tubes as follows:

1—RCA-1624 as crystal or master oscillator
1—RCA-1624 as first buffer amplifier or frequency multiplier
1—RCA-1624 as second buffer amplifier or frequency multiplier
2—RCA-813 as power amplifiers

6. *Type of Circuit.* The general circuit arrangement is shown in Figure 13–15. The oscillator frequency is controlled by means of a continuously variable inductor for the band of 1500 to 3000 kc. The oscillator inductor is provided with a veeder-root counter and a 6¾-inch diameter vernier scale so that a high degree of reset accuracy may be obtained. A panel control switch in the oscillator circuit permits selection of any one of the crystals, or instant change to master oscillator operation.

A ganged nine-position frequency switch is used to select simultaneously the appropriate values of inductance in the first buffer, second buffer, and power amplifier tank circuit. The variable tuning condensers in the first and second buffers are also ganged to quick and convenient adjustment. A separate variable tuning condenser is provided for resonating the power amplifier tank circuit.

Coupling between the power amplifier tank and antenna circuits is obtained by means of panel controls which may be adjusted to insert various values of inductance or capacitance, or both, so that the power amplifier tubes may be loaded into shipboard antennas whose characteristic impedance varies over wide limits between 2000 and 24,000 kc.

For keying the transmitter, a quick-acting keying relay is employed which is arranged to key all stages in the transmitter. For A–2 emission, a suitable modulation transformer is built into the transmitter for modulating the power amplifier plate circuit. The primary of the modulation transformer obtains its input from a 500-cycle generator, the latter being a part of the main motor generator, as explained further in this chapter.

7. *Power Supply.* For shipboard installations where the ship's power supply is 115 volts d.c. and where the ET–8023 transmitter is installed in conjunction with a model 3U or model 4U radio unit, no additional motor generator is required. An M.G. transfer switch in frame D, which includes the model ET–8023, is used to transfer the motor generator circuits either to the ET–8023 transmitter or ET–8024–A intermediate-frequency transmitter.

Attention is invited to the fact that the ET–8023 transmitter assembly provides for complete control of the motor generator unit already available with the ET–8024–A transmitter. In other words, the ET–8023 panel provides for adjustment of filament and plate voltage from the motor generator, as well as adjustment of the power output by means of the plate voltage control. Filament and plate voltmeters are provided on the ET–8023 panel, as well as plate current and P.A. grid meters.

8. *The Crystal Switch.* The crystal switch has eleven positions. The first ten positions are used to select the appropriate crystal. The eleventh position is to provide master oscillator operation. Normally the ET–8023 transmitter is furnished with four crystals, 2070, 2080, 2760 and 2765 kc. These four crystals are to be placed in crystal jacks 1, 2, 3 and 4 respectively, which will connect the 2070-kc crystal to position 1 and the 2765 crystal to position 4 on the CRYSTAL SWITCH. Switch positions 5 and 10 inclusive will not normally be used unless additional crystals are added in the future.

The oscillator tuning control actuates a rotating coil having 29 turns. A veeder-root counter marked "A" is driven from the rotating coil shaft. This counter reads 000 for the lowest oscillator frequency and 280 for the highest oscillator frequency. The first two digits on the counter indicate complete turns. The third or right hand digit indicates "tenths" of a turn. A 0–360 division dial marked "B" is connected directly to the rotating shaft of the oscillator coil. Therefore, the oscillator cali-

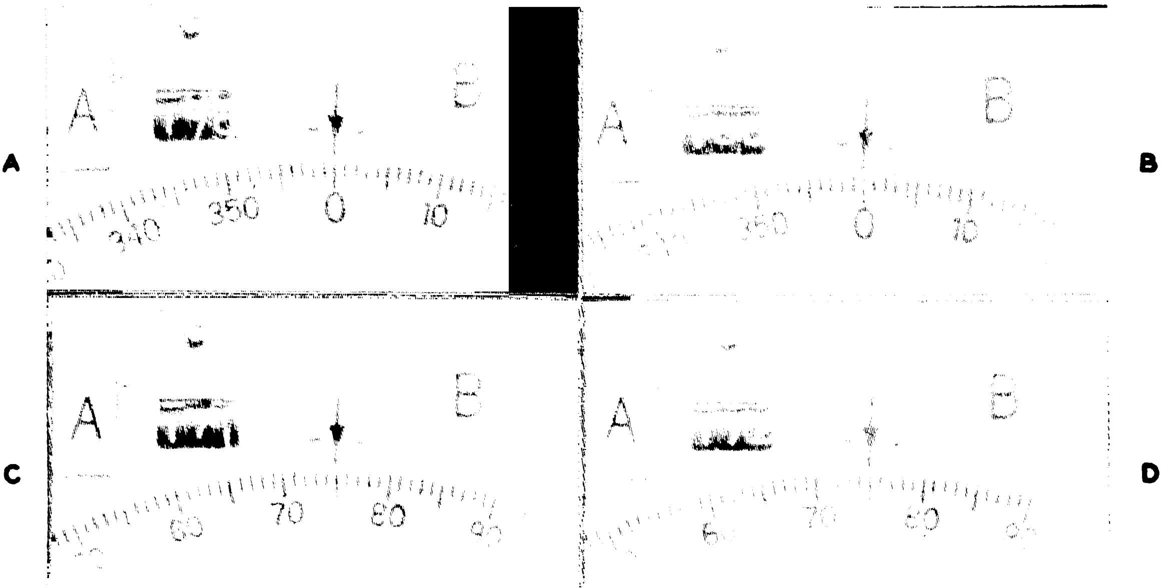


FIG. 13–16. In illustrations (a) and (b) dial B is at zero. Counter A may be recorded and used either at 179 or 180. In illustrations (c) and (d) dial B is at 75. Counter A may be recorded and used either at 171 or 172.

bration for any frequency is recorded by means of counter "A" and dial "B."

Movement of dial "B" every 36 divisions (one tenth of a coil turn) causes counter "A" to change by one digit. Inherent backlash in the counter gears will allow a small variation in the second and third digit. However, this will not result in any error in the oscillator calibration because dial "B" accurately determines fractional positions of the rotating coil. To understand this the examples shown in Figure 13–16 should be noted.

For the seventeen output frequencies provided by the four standard crystals, refer to the calibration table below. A duplicate of this table is mounted on the transmitter panel, and the last five columns (P.A. Tuning, Coupling, etc.) are to be filled in by the installation personnel who will determine the appropriate settings at the time of installation. Instructions for determining the correct settings for the last five columns of the table are given further in this chapter.

The tuning key located below the oscillator control should always be used to key the transmitter when making adjustments. This will prevent overload on the tubes during periods when the P.A. Tuning, Coupling, etc., may be out of adjustment.

FIG. 13-17. CALIBRATION TABLE FOR ET-8023 TRANSMITTER

Output Freq. (*kc*)	Band Sw.	Xtal. Sw.	Osc. Tuning		Buf. Tun.	Pa. Tun.	Coup.	Ant. Sw.	Ant. Cap.	Ant. Ind.
			A	B						
4,140	3	1	173	120	26					
4,160	3	2	175	180	26					
5,520	4	2	251	51	29					
5,530	4	4	251	67	29					
6,210	4	1	173	120	38					
6,240	4	2	175	180	39					
8,280	5	1	173	120	35					
8,320	5	2	175	180	35					
11,040	6	3	251	51	35					
11,060	6	4	251	67	35					
12,420	7	1	173	120	23					
12,480	7	2	175	180	23					
16,560	8	3	251	51	22					
16,590	8	4	251	67	22					
16,640	8	2	175	180	23					
22,080	9	3	251	51	27					
22,120	9	4	251	67	27					

To place the ET-8023 transmitter on the air, proceed as follows:

(a) Place AUTO ALARM MASTER SWITCH in position 3 if main antenna is to be used, or position 2 if emergency antenna is to be used.
(b) Place TRANSMITTER SELECTOR SWITCH in position 1.
(c) Place MOTOR GENERATOR TRANSFER SWITCH in ET-8023 position (left hand position).
(d) Start motor generator and adjust filament voltage to 10 and plate voltage to 1400.
(e) Place EMISSION SWITCH in A1 position (continuous waves).
(f) Determine output frequency desired and set the BAND SWITCH, CRYSTAL SWITCH, OSCILLATOR TUNING "A" AND "B" and BUFFER TUNING, from the calibration card.
(g) Now press TUNING KEY and readjust BUFFER TUNING slightly until the P.A. GRID CURRENT meter reads maximum. The correct setting for the BUFFER TUNING should be reasonably close to the value shown on Tuning Table.
(h) Now set P.A. TUNING, COUPLING, ANTENNA SWITCH, ANTENNA CAPACITOR and ANTENNA INDUCTOR from the Tuning Table. Then slightly readjust P.A. TUNING for *minimum* current as read on the P.A. CATHODE CURRENT meter. The P.A. grid current will increase when P.A. TUNING is adjusted for minimum cathode current. The calibrated settings of the ANTENNA INDUCTOR is indicated by a veeder-root counter to the left of the ANTENNA INDUCTOR control.
(i) The normal telegraph key should then be closed, which will cause the transmitter to draw its normal full load and which will give a minimum P.A. cathode current between approximately 3/10 to 4/10 amp.
(j) After the transmitter has been correctly adjusted as outlined above for A1 emission (continuous wave), the EMISSION SWITCH may be thrown to the A2 position if transmission is desired using modulated wave output.

9. *ET-8023 Output Circuit.* Figure 13-18 shows the three antenna circuit combinations which can be selected with the ANTENNA SWITCH on the front panel of the ET-8023 transmitter.

The ANTENNA SWITCH position to be used will be determined by the antenna and the frequency. However it is suggested that the transmitter be calibrated for the lowest ANTENNA SWITCH position that will permit the transmiter to load into the antenna.

Figure 13-18a shows the antenna capacitor and the antenna inductor disconnected from the antenna circuit. The slider and both ends of the antenna inductor are grounded to prevent the antenna inductor from resonating with stray capacitances at the higher frequencies. The ANTENNA SWITCH in position 1 places the coupling capacitor in series with the antenna.

To load transmitter with ANTENNA SWITCH in position 1:

(a) Set COUPLING at 25 (half scale).
(b) Set ANTENNA INDUCTOR at 222.
(c) Adjust P.A. TUNING for minimum cathode current. If minimum cathode current is less than .3 amp, reset COUPLING to a higher number and readjust P.A. TUNING for minimum cathode current. Set COUPLING to a lower number if minimum cathode current is more than .4 amp.

If the transmitter will not load properly with any setting of the coupling, it will be necessary to try position 2 of the ANTENNA SWITCH.

Figure 13-18b shows the antenna connected to the slider on the antenna inductor. The counter DIAL geared to the antenna inductor reads 000 to 444. When this dial reads 000, the slider is at the end of the inductor which connects to the coupling capacitor.

To load transmitter with ANTENNA SWITCH in position 2:

(a) Set COUPLING at 25 (half scale).
(b) Set ANTENNA INDUCTOR at 000.
(c) Adjust P.A. TUNING for minimum cathode current. If minimum cathode current is less than .3 amp or more than .4 amp, reset ANTENNA INDUCTOR to 010 or 020 and readjust P.A. TUNING for minimum cathode

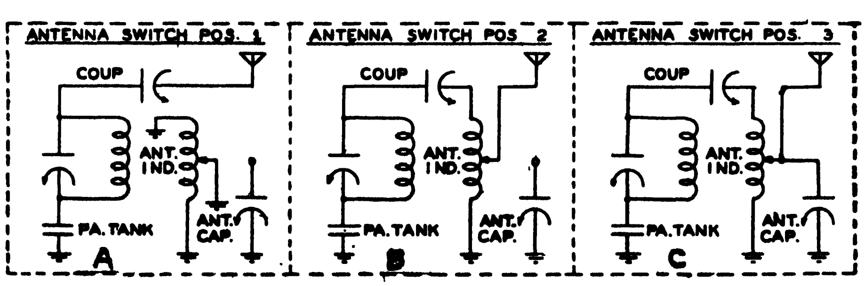


FIG. 13-18. The three antenna circuit combinations which can be selected with the front panel antenna switch of the ET-8023 transmitter.

current. Repeat this operation as often as necessary, using higher numbers of the ANTENNA INDUCTOR each time to get the desired cathode current. Once the approximate setting of the ANTENNA INDUCTOR is obtained, the ANTENNA INDUCTOR can be calibrated at some whole number and the COUPLING CAPACITOR adjusted for the exact loading.

Figure 13–18c shows the antenna capacitor connected in parallel with the whole or part of the antenna inductor, depending on the position of the slider.

To load transmitter with ANTENNA SWITCH in position 3:

(a) Set COUPLING at 25 (half scale).
(b) Set ANTENNA INDUCTOR at 000.
(c) Set ANTENNA CAPACITOR at 25.
(d) Adjust P.A. TUNING for minimum cathode current. If minimum cathode current is less than .3 amp, reset the ANTENNA INDUCTOR to a higher number and readjust P.A. TUNING for minimum cathode current. Repeat this operation as often as necessary, using higher numbers on the ANTENNA INDUCTOR each time. For frequencies near 2 mc, it may be necessary to set ANTENNA CAPACITOR at 40 or 50 instead of 25 as shown above. The ANTENNA CAPACITOR should be set preferably less than 25 for frequencies above 10 mc. Once the approximate setting of the ANTENNA INDUCTOR is obtained, the ANTENNA INDUCTOR can be calibrated at some whole number and the COUPLING CAPACITOR or ANTENNA CAPACITOR can be adjusted for the exact loading.

With the ANTENNA SWITCH in position 3, extremely high voltages can be built up in the resonant circuit formed by the antenna inductor and the antenna capacitor. This is especially pronounced when the transmitter is not loaded such as could happen when the antenna is not connected to the transmitter. Damaged insulation may result if these voltages were allowed to persist. If there is any indication of flash-over in the antenna circuit components, it is advisable to try new settings of the antenna inductor, antenna capacitor or coupling.

10. *Oscillator Alignment.* The following adjustment procedure is made at the factory and should not be disturbed unless major repairs or replacements are required in any of the oscillator components:

The oscillator alignment frequency is 3000 kc with counter "A" adjusted to 270 and dial "B" to 5. Crystal switch should be in M. O. position. A precision frequency meter adjusted to 3000 kc should be used. Then loosen locknut on variable condenser C–732 which is located at left side of oscillator compartment and adjusted through the opening below the crystal mounting panel. C–732 should then be very carefully adjusted, using an insulated screwdriver, for 3000 kc, without disturbing the setting of counter "A" at 270 and dial "B" at 5. Condenser locknut should then be tightened.

Use low plate voltage and keep clear of live circuits when making oscillator adjustment. The moving slider of the oscillator rotating coil must not be displaced. This slider should be against the rear stop (29th turn) when counter "A" reads between 289 and 290.

13–2f. RMCA Model ET–8024A Main Radiotelegraph Transmitter (Component of 4U Radio Unit)—The model ET–8024–A radiotelegraph transmitter is designed primarily for shipboard applications where a modern, medium-power, intermediate-frequency main transmitter is required. The complete transmitter is used as an integral component of frame B in radiomarine model 4U radio unit.

1. *Rating.* The ET–8024–A is designed to deliver 200 watts or more to a standard 750-micromicrofarad, 4-ohm antenna. A1 (continuous waves) or A2 (modulated waves) emission may be quickly selected by means of a toggle switch on the front panel. For A2 emission, a modulation frequency of approximately 500 cycles is used, and a modulation percentage between 70 and 100 percent is maintained. The frequency tolerance for either A1 or A2 emission is better than 0.3 percent.

2. *Frequency Range.* The ET–8024–A is designed for eight frequencies in the band 350 to 500 kc. The eight frequencies normally provided are 355, 375, 400, 410, 425, 454, 468 and 500 kc.

3. *Vacuum Tubes.* A total of three vacuum tubes are used in the transmitter. The master oscillator uses one 1624 tube. The power amplifier uses two 813 tubes, connected in parallel. Both types of tubes are of the quick heating type, thereby permitting the transmitter to be immediately keyed as soon as the motor generator comes up to speed, a period of approximately five seconds.

4. *Power Supply.* The transmitter is designed to operate from a shipboard power supply of 115 volts d.c., plus or minus 15 volts. This power supply operates the transmitter motor generator mounted in the base of Frame D.[1] The motor generator is a compact three-unit two-bearing machine with ball bearings. The motor is designed for operation from the 115 volt d-c line, and the output of the machine is approximately as follows:

1400 volts, .45 amp d.c. for plate supply
80 volts, 2.5 amp, 83 cycles, for filament supply
140 volts, 2 amp, 500 cycles, for A2 modulation

5. *Type of Circuit.* The ET–8024–A transmitter utilizes a master oscillator-power amplifier circuit,

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[1] Motor generator, starter and motor generator transfer switch are mounted in frame D of model 4U to simplify wiring and to permit ET–8023 high-frequency transmitter to be switched to the motor generator.

with plate modulation of the power amplifier tubes for A2 emission. The complete circuit arrangement is shown in Figure 13–19.

The 1624 oscillator tube and its associated component parts are housed in a separate shielded compartment in the lower left section of the frame. There are eight oscillator inductors, one for each operating frequency, each inductor being provided with an adjustable iron core which is locked for the desired pretuned frequency. Oscillator screen and plate voltages are obtained from appropriate taps on a voltage divider connected across the 1400-volt d-c generator. The oscillator circuit may be used either as a self excited master oscillator or as a crystal controlled oscillator. One to eight type R3 crystals may be installed at any time by removing the jumpers across the studs on the crystal mounting panel and then mounting the type R3 crystals on the studs.

The two 813 power amplifier tubes receive their control grid excitation from the tank circuit of the 1624 oscillator. The plate circuit of the power amplifier tubes is provided with a tuned tank, the tank inductor being tapped for the eight pre-tuned frequencies. An adjustable iron core, in the P.A. tank inductor, is also provided for general lineup purposes, after which the core is locked in position. A modulation transformer is used to plate modulate the power amplifier tubes for A2 emission. This transformer has its secondary winding connected in series with the high-voltage d-c plate circuit of the power amplifier tubes, while the primary winding is connected to the 500-cycle alternator on the motor generator set.

The antenna circuit of the transmitter consists of a tapped loading coil, with the taps brought out to a four-position antenna inductance switch, while for close adjustment of antenna tuning, an antenna variometer is provided. This flexible arrangement permits front panel control of antenna loading for any value of inductance from 32 to 380 microhenries, and enables the transmitter to be used, in an emergency, on a temporary antenna, or the emergency transmitting antenna, without any internal changes in the transmitter. In other words, the transmitter may be quickly resonated to the distress frequency of 500 kc in the event that a temporary emergency antenna has to be erected.

The antenna circuit is coupled to the power amplifier tank circuit through low reactance capacitors, which are common to both circuits, and which function to efficiently transfer the power amplifier energy to the antenna circuit, and, at the same time, to by-pass the radio frequency harmonics which are normally present in any high efficiency Class C power amplifier. Since the power amplifier tank circuit is tuned at all times to the oscillator frequency, the power amplifier tubes are automatically protected against overload or excessive voltages in the event that the antenna circuit is detuned, or grounded, or opened.

Break-in operation is provided by means of a break-in relay which "keys" the transmitter circuits and automatically transfers the antenna circuit to the radio receiver each time the key is opened. The break-in relay is capable of keying speeds up to 50 words per minute.

6. *Antenna Characteristics.* The design of the transmitter is such that it will cover the specified frequency range on any antenna whose characteristics fall between 600 and 1500 $\mu\mu$f, and a resistance of 2 to 10 ohms. Power rating is based on the standard Federal Communications Commission antenna of 750 $\mu\mu$f and 4 ohms.

7. *Panel Controls.* To start the transmitter, a toggle switch for motor generator start-stop is provided. When this switch is thrown to the "start" position, it energizes the automatic motor starter, quickly bringing the motor generator up to speed.

To select A1 or A2 emission, it is simply necessary for the radio operator to throw the A1–A2 switch to the appropriate position.

For selection of frequency, there is provided an eight position frequency switch, plainly marked in kilocycles for each of the eight pre-tuned frequencies. This frequency switch simultaneously selects the appropriate oscillator tank inductor (also crystal when used), and the tap on the power amplifier tank inductor.

For resonating the antenna circuit, the operator chooses the appropriate position of the antenna inductance switch, and then resonates the antenna variometer for maximum antenna current.

To regulate the filament voltage on the tubes, there is provided a filament rheostat which is connected in the primary circuit of the filament transformer.

To adjust the plate voltage and 500-cycle alternator voltage, a two-section plate rheostat is provided. This rheostat provides a quick and convenient means of adjusting the transmitter for normal full power operation or, whenever desired, the power may be reduced to approximately one-half normal as required by F.C.C. regulations.

A pilot light on the transmitter panel is used to indicate when the motor generator is running.

A tuning card and mounting frame on the transmitter panel are furnished so that a suitable record may be made of the various controls for the eight operating frequencies.

8. *Metering Facilities.* Five meters are mounted on the lower section of the transmitter front panel. The function of each meter and its rating are as follows:

Filament voltmeter	0–15 volts a.c.
Antenna ammeter	0–15 amp r.f.
Plate voltmeter	0–2 kilovolts (2000 volts)
P.A. cathode ammeter	0–1 amp d.c.
Line voltmeter	0–150 volts d.c.

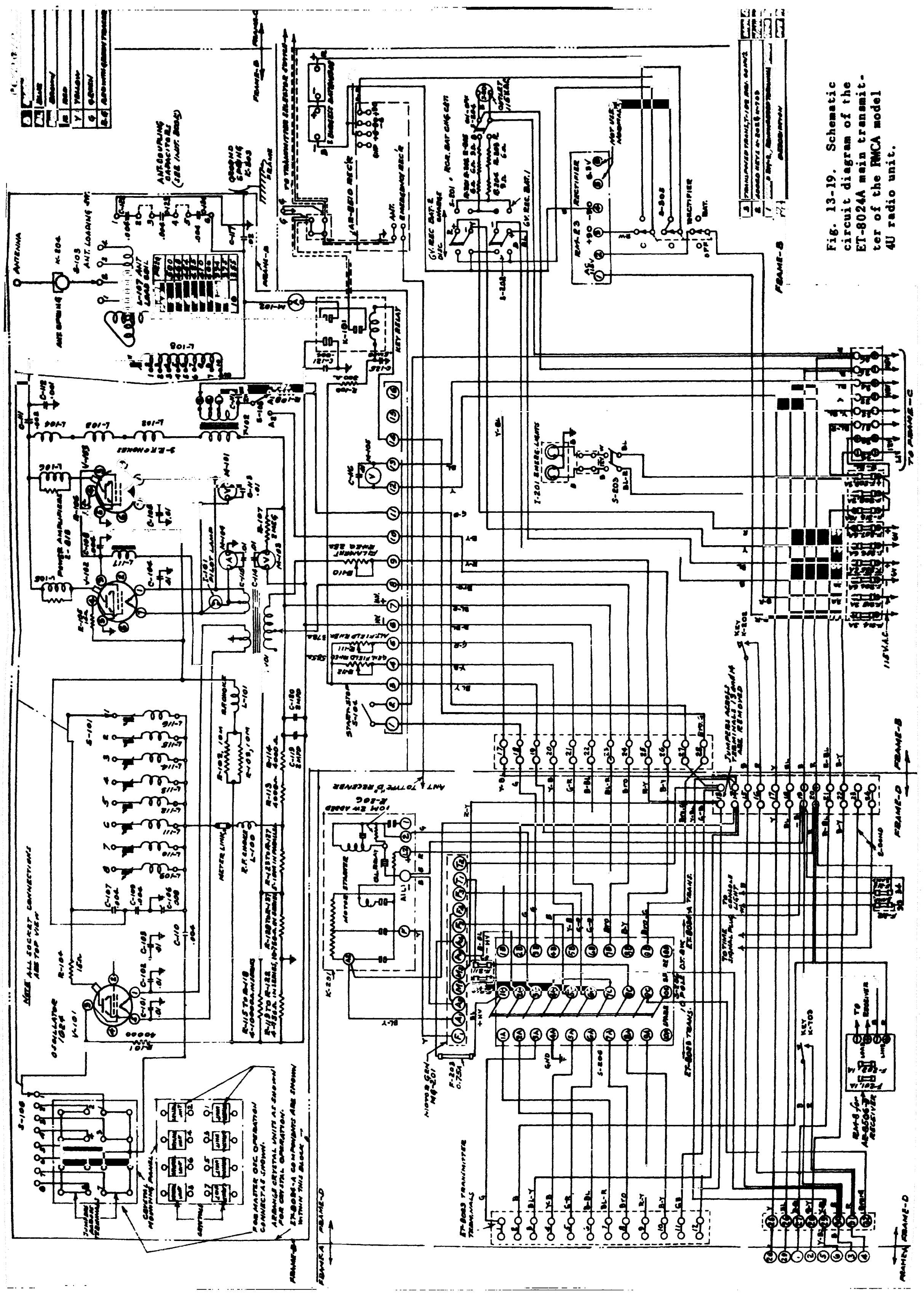


Fig. 13-19. Schematic circuit diagram of the ET-8024A main transmitter of the RMCA model 4U radio unit.

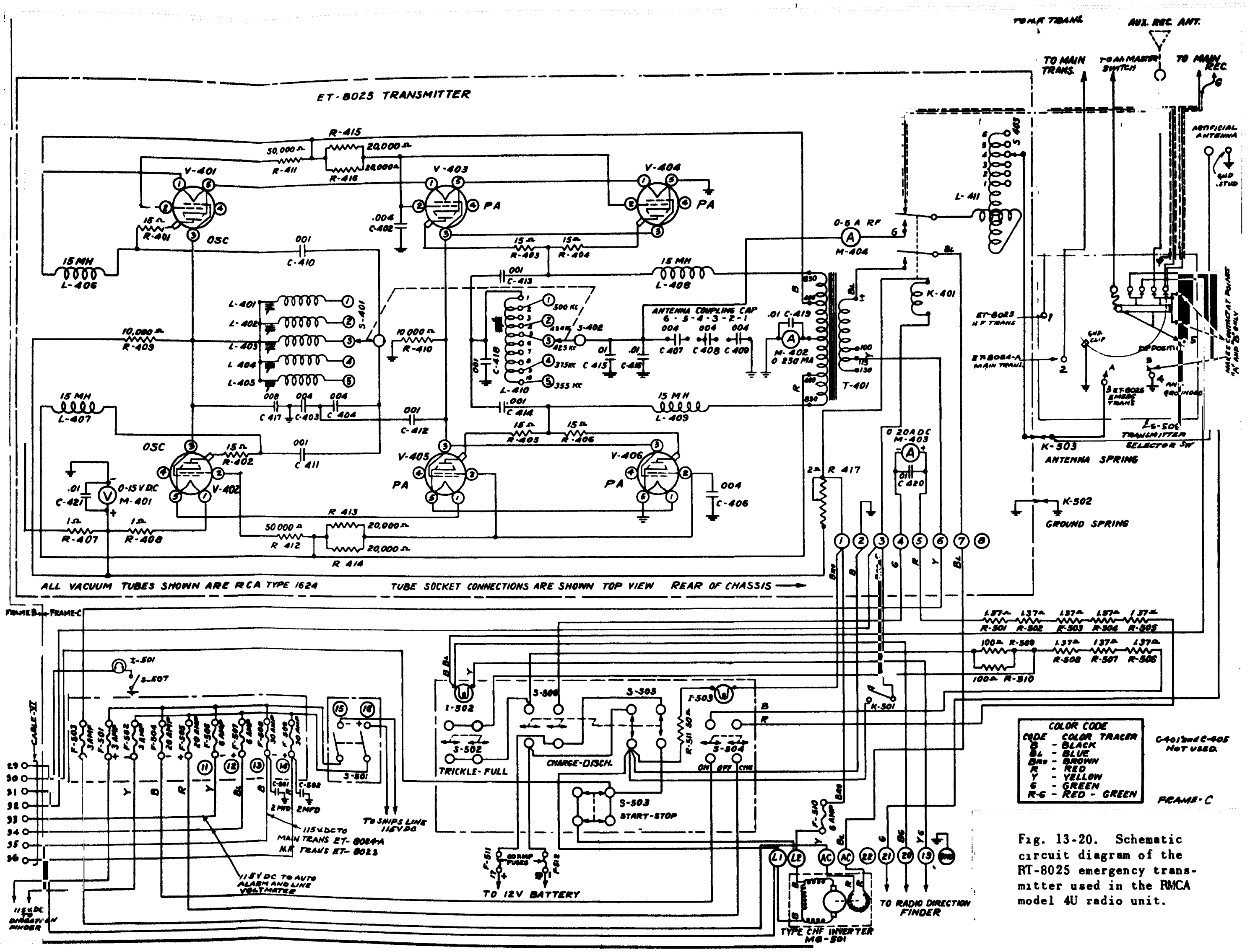


Fig. 13-20. Schematic circuit diagram of the RT-8025 emergency transmitter used in the RMCA model 4U radio unit.

9. *General O*

(a) Place AU A) in p (Main A
(b) Place TR. C) in po
(c) Place MO (frame in ET-80

Note: All of a operator comes ready to go on a mitter break-in r places the auto a

(d) Start mo STOP-STAR
(e) Adjust fil
(f) Adjust pl
(g) Place fre sired oper emission.
(h) Place ant 1, 2, 3 or chart on
(i) Close tele, ometer fo transmitte communic
(j) After con is recomn reduced sc interferen To reduce to lower t 1200 volt tion, the p further interferen tubes and
(k) *Important* tenna may the emerge instructior master sw to connec ET-8024-A ET-8024-A sion, so th tress trans

10. *Installation* it will not be nece ments inside the t ard installation justed and lined u the eight standar coupling is alread

Before making are outlined in d

9. *General Operating Instructions.*

(a) Place AUTO ALARM MASTER SWITCH (frame A) in position 3 (Transmitting Position) (Main Antenna).

(b) Place TRANSMITTER SELECTOR SWITCH (frame C) in position 2 (ET–8024–A Main Trans.).

(c) Place MOTOR GENERATOR TRANSFER SWITCH (frame D at left of AR–8506–B receiver) in ET–8024–A position.

Note: All of above switching may be done at time operator comes on duty. This makes ET–8024–A ready to go on air, connects antenna through transmitter break-in relay to AR–8510 receiver, and also places the auto alarm storage battery on charge.

(d) Start motor generator. (Break seal on STOP-START switch when authorized.)

(e) Adjust filament voltmeter to 10 volts.

(f) Adjust plate voltmeter to 1400 volts.

(g) Place frequency switch in position for desired operating frequency. Select A1 or A2 emission.

(h) Place antenna inductance switch in position 1, 2, 3 or 4, as required. Refer to tuning chart on front panel.

(i) Close telegraph key and adjust antenna variometer for maximum antenna current. The transmitter is now ready for normal two way communication.

(j) After communication has been established, it is recommended that the antenna power be reduced somewhat so as to avoid unnecessary interference, as required by F.C.C. rules. To reduce power, adjust the plate rheostat to lower the voltage from 1400 volts, to say 1200 volts. For short distance comunication, the plate voltage should be reduced still further. This procedure not only minimizes interference, but also increases the life of the tubes and other parts of the equipment.

(k) *Important:* In an emergency the main antenna may be disabled, requiring the use of the emergency antenna. All of the foregoing instructions apply except that the auto alarm master switch should be placed in position 2 to connect the emergency antenna to the ET–8024–A. It is good practice to keep the ET–8024–A adjusted for 500 kc, A2 emission, so that it is quickly available for distress transmission.

10. *Installation Adjustments.* As a general rule, it will not be necessary to make any major adjustments inside the transmitter for the average standard installation. The transmitter is carefully adjusted and lined up at the factory for operation on the eight standard frequencies, and the antenna coupling is already adjusted for a typical antenna.

Before making any internal adjustments, which are outlined in detail below, the installation man should operate the set, into the antenna, on each of the eight frequencies, and observe the reading on the P.A. cathode ammeter. For normal operation, with filament voltage adjusted to 10 volts and plate voltage adjusted to 1400 volts, the P.A. cathode meter should read approximately .4 amp when the antenna variometer and antenna inductance switch have been adjusted for maximum antenna current. If the P.A. cathode ammeter reads more than approximately .42 amps, this indicates that the antenna coupling should be decreased. If the P.A. cathode ammeter reads less than approximately .35 amp, the antenna coupling may be increased.

Warning: The voltages present inside the transmitter, when the motor generator is running, are dangerous to human life, and, therefore, *extreme caution* should be observed at all times not to reach inside the transmitter unit unless the motor generator has been shut down. Make it a rule to *always* shut down the motor generator whenever the transmitter unit is swung out on its hinges, or when inserting tubes, making adjustments, changing fuses, etc.

Refer to Figure 13–19 and the following description for an understanding of the antenna coupling arrangement:

The main antenna coupling condenser C–117, which always remains in circuit, is a large .02-μf unit. The adjustable antenna coupling condensers are three in number, C–122, C–123 and C–124, each a .004-μf unit. These three condensers may be left out of circuit entirely for the highest coupling condition, or they may be connected in various series, or parallel arrangements, across the main .02-μf condenser, to lower the coupling.

The following tabulation indicates the six possible arrangements (A to F) for the three .004-μf condensers. These three condensers are mounted near the upper right-hand section of the oscillator shielded compartment, and are furnished with sufficient flexible strap connectors to permit any of the six combinations listed below to be obtained:

Condenser Arrangement	*Terminal Connections*
A—None in use	Remove all straps
B—Three in series	Strap 2 to 3 and 4 to 5
C—Two in series	Strap 2 to 5
D—One in parallel	Strap 2 to 6
E—Two in parallel	Strap 2 to 6 and 1 to 5
F—Three in parallel	Strap 1 to 5, 1 to 3, 2 to 4 and 2 to 6

Arrangement A gives highest coupling. Arrangement F gives lowest coupling. Other arrangements give intermediate values of coupling.

Any large change in antenna coupling condensers, as compared to original factory arrangement, will require a new setting for the P.A. tank inductor iron core. To determine this, the antenna should be grounded or disconnected (use transmitter selector switch) and then ***minimum*** P.A. cathode current should be checked as follows:

(a) Ground or open antenna, and adjust plate voltage to 1400.
(b) Operate set at 355 and 500 kc and record P.A. cathode current.
(c) If P.A. cathode current is less than .15 amp, no changes are needed.
(d) If P.A. current exceeds .15 amp, shut down set, unlock P.A. core screw and move screw in or out a small amount.
(e) Operate set again, record P.A. current on 355 and 500 kc, and repeat operation (d) until the *best possible minimum* value is obtained on both frequencies.
(f) Shut down set and lock core adjusting screw.
(g) Operate set and check all eight frequencies for minimum cathode current.
(h) Connect antenna, load out set, and check that P.A. cathode current does not exceed approximately .42 amp.

Each of the eight oscillator inductors are carefully calibrated at the factory for master oscillator operation, using precision crystal standards. Normally these adjustments should not be disturbed at any time. If it is ever required to readjust any of the oscillator frequencies, it is important to use an accurate frequency meter loosely coupled to the antenna circuit. The oscillator core adjusting screw should be temporarily unlocked, the core moved in or out a little as required, and the antenna circuit adjusted to resonance for each frequency to be calibrated. For such adjustments, it is recommended that the plate voltage be reduced to approximately 1000 volts. After the oscillator cores have been finally adjusted, care should be taken to tighten the locknut on each adjusting screw.

Install type R3 crystals (one to eight) by removing jumper connections on crystal mounting panel in oscillator compartment and connecting the crystals on the mounting studs provided. Mount the four crystals *nearest* the front panel with the nameplate inverted (frequencies 1–3–5 and 7), and mount the other four crystals (frequencies 2–4–6 and 8) with the nameplate normal. This maintains the upper crystal electrodes and nameplates nearest ground potential. Normally the crystal for frequency 1 will be 355 kc and for frequency 8 it will be 500 kc, with the remaining crystals in the proper order between 2 and 7. If desired, any one or more frequencies may be used for master oscillator operation by leaving jumpers in place, removing jumpers only for frequencies to be crystal controlled.

Connect a 0–50-ma d-c meter across the meter link terminal in oscillator compartment, removing the link temporarily. Place frequency switch in correct position for oscillator tank iron core to be adjusted. Start transmitter and adjust plate voltage to about 1000 volts. Close key and slowly adjust iron core with screwdriver until 0–50-ma meter reads minimum (about 24 ma). Then turn adjusting screw about one-half turn *counterclockwise* (core moves out) which will raise meter reading about 1 ma. Listen with receiver to beat note and key transmitter to check that note is clean and stable. When the crystal "locks in" the oscillator, a small change in the adjusting screw will not change the beat note appreciably. If the screw is tuned clockwise too far (core moves in), the crystal will lose control and the circuit will act as a master oscillator with rapid change in beat note as screw is turned. On the other hand, turning screw too far counterclockwise may reduce the oscillator drive to the power amplifier. After best stable adjustment is obtained, tighten locknut on screw and proceed to adjust the oscillator cores for the other frequencies to be crystal controlled. Remove meter and tighten link when all adjustments are completed.

Check all final adjustments with the transmitter loaded out into antenna, with transmitter panel in its normal vertical position.

11. *Tuning Card Record.* The installation man should fill in the tuning card on the transmitter panel for each of the eight operating frequencies so that the radio operator will have a convenient record of the settings for the antenna inductance switch and the antenna variometer. Also record 500-kc adjustments when the *emergency transmitting* antenna is used.

12. *Maintenance.* The commutators and collector rings of the motor generator should be kept clean at all times. Brushes should slide freely in their holders and make good contact with the commutators or collector rings. Commutators which are in good condition should be free from excessive grooves or scratches and present a smooth light brown appearance. If it is necessary to sand commutators or collector rings, use fine sandpaper No. 00 or finer. Do not use emery cloth, as such materials contain metallic particles which will introduce short circuits between commutator bars. Normally commutators and collector rings may be "buffed" with a piece of canvas.

Warning: When working around the motor generator, keep clear from the high-voltage (1400 volt) circuits. If it is necessary to sand the high voltage commutator with the machine running, be sure to disconnect the high voltage generator field lead F2.

The ball bearings of the motor generator should be lubricated about every six months. When lubricating ball bearings, extreme care must be taken not to overgrease. Bearings which are packed too tightly with grease will overheat. Recommended procedure is to remove the drain plug at the bottom of each bearing, and then insert a small amount of grease through the upper grease plug. After greasing, the machine should be run for a few minutes before replacing drain plugs in order to remove any excess grease pressure on the bearings. A light sodium base grease is recommended, and a tube of such grease is furnished with each machine. Any bearing which gives evidence of overheating (probably from dirt in grease) should be removed and the bearing washed in gasoline or carbon tetrachloride, repacked lightly with grease and then replaced. Do not allow grease to accumulate on or around brush holders, commutators or collector rings.

The contacts on the automatic motor starter should be examined from time to time to determine if they are in good condition. A reasonable amount of contact wear and tear, due to usage, is to be expected. If contacts are badly pitted, they may be dressed down with a fine clean file or with sandpaper. Contacts should be wiped clean to free them from filings or other harmful material after being dressed.

The time delay mechanism of the automatic motor starter is adjusted so that the unit completes its cycle in approximately four seconds. Do not tamper with this adjustment to reduce the starting time.

The oscillator and power amplifier frequency switches (geared together) and the antenna inductance switch should operate freely at all times and be kept clean around the contacts and insulation. After considerable use, if it is noted that the contacts tend to "grind," a very small amount of light grease or vaseline may be applied. A small amount of lubricant applied directly to the contacts will provide smooth action, but care must be taken not to use excessive amounts as this may result in high resistance contacts. Occasionally put two or three drops of light oil on the switch shafts where they rotate in their bearings.

The break-in relay must be kept in good adjustment so that it operates with small contact clearance and minimum sparking. When this relay is properly adjusted, no sparking should occur between the upper right hand pair of contacts (antenna circuit), and only slight sparking should be observed at the upper left pair of contacts (keying circuit). Make sure that the lower center contacts, which connect the antenna circuit to the receiver, are always *opened* when the relay coil is energized.

From time to time observe that all tubes are located firmly in their sockets, and that the plate connection at the top is properly made. The contacts which connect the antenna circuit to the transmitter (upper right-hand frame section) are heavily silver plated, and should not be cleaned with abrasive material. A slightly darkened surface on these contacts is normal, and if cleaning is required, use a cloth soaked in carbon tetrachloride or gasoline. Keep the frame "ground spring" contacts (at rear) clean in a similar manner.

All interior parts of the transmitter should be kept clean and free from dirt, especially wherever high potential exists such as on the antenna inductance switch, antenna contacts, etc.

13. *Clock Mounting.* The front panel of the ET-8024-A provides space for a standard Chelsea radio room clock. This clock is ordinarily furnished by the U. S. Maritime Commission.

14. *Fusing.* A fuse panel, which is mounted in the lower-rear section of frame D above the motor generator unit, contains the following fuses:

F-201—RM-8 line fuse for AR-8506-B receiver, 1 amp, 250 volt, type 3-AG glass
F-202—RM-8 line fuse for AR-8506-B receiver, 1 amp, 250 volt, type 3-AG glass
F-203—high-voltage generator fuse, .75 amp, 300 volt, Cat. 2113
F-210—collector ring fuse, std., 3 amp, 250 volt, renewable
F-211—500-cycle alternator fuse, std., 3 amp, 250 volt, renewable
F-212—115-volt console light fuse, 3 amp, 250 volt, renewable
F-213—115-volt console light fuse, 3 amp, 250 volt, renewable

The following fuses are in lower section of frame B:

F-208—12-volt emergency light fuse, 3 amp, 250 volt, renewable
F-209—12 volt emergency light fuse, 3 amp, 250 volt, renewable
F-204—battery 1 (6-volt) fuse, 6 amp, 250 volt, renewable
F-205—Battery 1 (6-volt) fuse, 6 amp, 250 volt, renewable
F-206—Battery 2 (6-volt) fuse, 6 amp, 250 volt, renewable
F-207—Battery 2 (6-volt) fuse, 6 amp, 250 volt, renewable
F-214—115-volt a-c line fuse, 3 amp, 250 volt, renewable
F-215—115-volt a-c line fuse, 3 amp, 250 volt, renewable

Important: When replacing renewable fuse links in the various standard 250-volt, 2-inch fuse cartridges, be sure to use the correct fuse link rating as tabulated above. All fuses are plainly marked with an identification strip.

15. *Frame B Components.* The frame, in which the model ET-8024-A is mounted, is known as frame B. In addition to the ET-8024-A main transmitter, frame B provides for the installation of a model AR-8510 main receiver, the 90-volt B battery for this receiver, and also the receiver battery control and charging panel and a type RM-23, 90-volt, rectifier unit. A 115-volt d-c convenience outlet is also provided in the lower section of frame B.

Reference should be made to instructions for the AR-8510 main receiver and its associated circuits.

An emergency light is mounted in the top center section of frame "B" to provide illumination in the event of failure of the normal 115-volt d-c shipboard power supply. This emergency light operates from the 12-volt emergency storage battery that is furnished with the ET–8025 transmitter. The emergency light is turned on by means of a switch marked 12 V. EMERG. LIGHT which is mounted to the left of the AR–8510 receiver. Since the emergency transmitter battery may be on "charge," it is necessary to place this battery on "discharge" from the ET–8025 control panel (frame C). The emergency light assembly is a "dual" unit with sockets for two 21-candlepower 12-volt Mazda No. 1141 bulbs. A third "dummy" socket to hold a spare No. 1141 bulb is also provided.

16. *Important General Operating Notes.* Whenever the hinged front panel of the ET–8024–A transmitter is opened or closed, it should be firmly gripped by the handles provided. The weight of the transmitter is considerable and it *must not be permitted* to "slam" into the open (horizontal) or closed (vertical) positions. Stops on the frame will hold the unit when in the fully opened position. Always keep the panel upper clamping screws tight after closing panel.

The line voltmeter (0–150 volts) will read at all times, when ship's line voltage is available and when main line safety switch (in frame C) is closed. If line voltmeter does not read, check 30 amp fuses in frame C, and if these are O.K. advise engine room, or, in emergency, use ET–8025 transmitter.

The automatic motor starter is provided with a thermal overload cutout. Long continued overload will open this cutout. To close, depress the small bakelite bar to the left of the starter coil.

Whenever necessary, such as in an emergency, the ET–8024–A transmitter may be used with only one 813 power amplifier tube. When this is done, the plate voltage should be reduced to approximately 900 volts so that the single 813 power amplifier tube in use will not be overloaded.

13–2g. RMCA Model ET–8025 Radiotelegraph Transmitter (Component of 4U Radio Unit)— The model ET–8025 radiotelegraph transmitter is a compact, self-contained unit, designed for shipboard applications as an emergency intermediate frequency transmitter. The complete transmitter is mounted in a compact frame, including the emergency motor generator, the main line safety switch, fuse panel, and control and charging circuits for the external 12-volt emergency storage battery.

1. *Rating.* The ET–8025 is designed to deliver 40 watts or more to a standard 750-$\mu\mu$f, 4-ohm antenna. A2 (modulated waves) emission is provided by means of the 350-cycle output from the emergency motor generator. The full-wave, self-rectified circuits in the transmitter automatically provide substantially complete modulation, which, in turn, permits a pleasing 700-cycle note in the received signal. The frequency tolerance is better than 0.3 percent.

2. *Frequency Range.* The ET–8025 is designed for five frequencies in the band 350 to 500 kc. The five frequencies normally used are 355, 375, 425, 454 and 500 kc.

3. *Vacuum Tubes.* A total of six vacuum tubes are used in the transmitter. The master oscillator circuit uses two 1624 tubes. The power amplifier uses four 1624 tubes. The 1624 tube is a quick-heating tube, thereby permitting the transmitter to be placed on the air as soon as the emergency motor generator comes up to speed, a period of approximately five seconds.

4. *Power Supply.* The transmitter is designed to operate from the emergency 12-volt storage battery. No other power source is required. The 12-volt storage battery, which has a capacity of 44 amp for 6 hours, supplies energy to the transmitter filaments, break-in relay, and the emergency motor generator. The average total drain from the 12-volt storage battery, with the transmitter loaded into the antenna, key locked, is approximately 35 amp.

5. *Type of Circuit.* The ET–8025 transmitter utilizes a master oscillator—power amplifier circuit. The complete circuit arrangement is shown in Figure 13–20.

The two 1624 oscillator tubes and their associated component parts are mounted in the forward section of the transmitter sub-panel. There are five oscillator tank inductors, one for each operating frequency, each inductor being provided with an adjustable iron core which is locked for the desired pre-tuned frequency. Oscillator screen and plate voltages are obtained from appropriate taps on the plate transformer in the unit.

The four 1624 power amplifier tubes receive their control grid excitation from the tank circuit of the oscillator. Each pair of power amplifier tubes is connected in parallel for the conventional full wave self rectified circuit arrangement. The power amplifier plate circuit comprises a tank inductor with taps for each of the five pre-tuned frequencies. An adjustable iron core in the P.A. tank inductor is provided for general lineup purposes, and then locked in position.

The antenna circuit of the transmitter consists of a tapped loading coil, with the taps brought out to a six position antenna inductance switch, while for close adjustment of antenna tuning an antenna variometer is provided. This flexible arrangement permits front panel control of antenna loading for any value of inductance from 32 to 380 microhenries, and enables the transmitter to be used, in an emergency, on a temporary antenna without any internal changes in the transmitter. In other words, the transmitter may be quickly resonated to the distress frequency of 500 kc, in the event that a temporary emergency antenna has to be erected.

The antenna circuit is coupled to the power amplifier tank circuit through low reactance capacitors which are common to both circuits. This arrangement efficiently transfers the power amplifier energy to the antenna circuit, by-passes radio-frequency harmonics, and automatically protects the power amplifier tubes against overload in the event that the antenna circuit is detuned, opened or grounded.

Break-in operation is provided by means of a break-in relay which "keys" the primary circuit of the plate transformer and automatically transfers the antenna circuit to the radio receiver each time the key is opened. The break-in relay has a maximum speed of approximately 40 words per minute.

6. *Antenna Characteristics.* The design of the transmitter is such that it will cover the specified frequency range on any antenna whose characteristics fall between 600 and 1500 $\mu\mu$f, and a resistance of 2 to 10 ohms. Power rating is based on the standard Federal Communications Commission antenna of 750 $\mu\mu$f and 4 ohms.

7. *Panel Controls.* To start the transmitter, the 12-volt battery is placed on "discharge" by throwing the 12-volt battery switch to the position marked 12 V. BAT. ON DISCHARGE. The emergency motor generator is then started by means of the switch marked EMERG. MOTOR GENERATOR STOP-START.

For selection of frequency, the transmitter panel is provided with a five position frequency switch. This switch simultaneously selects the appropriate oscillator tank inductor and the tap on the power amplifier tank inductor.

For resonating the antenna circuit, the operator chooses the appropriate position of the antenna inductance switch, and then resonates the antenna variometer for maximum antenna current.

To regulate the filament voltage on the tubes, there is provided a filament rheostat and filament voltmeter.

To connect the main antenna to the emergency transmitter, the antenna transfer switch in the upper section of the frame is placed in the emergency position.

A red pilot light on the battery control panel indicates when the emergency motor generator is running.

An amber pilot light on the battery control panel marked D. F. SIGNAL LIGHT is provided to indicate when the bridge wishes to use the direction finder.

A switch on the battery control panel marked CHARGING RATE permits the 12-volt storage battery to be placed on full charge (approx. 9 amp) or on trickle charge (approx. 1.5 amp).

A switch on the battery control panel marked 12 V. BAT. CHARGING CIRCUIT permits the 115-volt d-c line to be disconnected from the charging circuit when it is not desired to charge the battery.

The ANTENNA TRANSFER SWITCH in the top section of frame C is a five-position switch marked: (1) ET-8023 HIGH FREQ. TRANS. (2) ET-8024-A MAIN TRANS. (3) ET-8025 EMERG. TRANS. (4) ANTENNA GROUNDED. (5) D. F. POSITION.

A tuning card and mounting frame on the transmitter panel are furnished so that a suitable record may be made of the various controls for the five operating frequencies.

8. *Metering Facilities.* Three rectangular case meters are mounted on the lower section of the transmitter front panel. A round case meter is mounted in the center section of the front panel. The function of each meter and its rating are as follows:

Charging ammeter (12 volt bat.)	0–20 amp d.c.
Filament voltmeter	0–15 volts d.c.
Antenna ammeter	0–5 amp r.f.
Cathode ammeter	0–250 ma d.c.

9. *General Operating Instructions.*

(a) Place AUTO ALARM MASTER SWITCH in position 2 (Emergency Antenna) or position 3 (Main Antenna).

(b) Place TRANSMITTER SELECTOR SWITCH in position 3 (ET-8025).

(c) Place CHARGE-DISCHARGE SWITCH in position marked 12 V. BAT. ON DISCHG.

(d) Start emergency motor generator by placing its START-STOP SWITCH in the START position.

(e) Adjust filament voltmeter to 10 volts.

(f) Place ANTENNA INDUCTANCE SWITCH in position for frequency desired, as recorded on tuning table.

(g) Close key and adjust antenna variometer for maximum antenna current. Resonance is also shown by maximum cathode current.

(h) To economize on battery drain, shut down emergency motor generator whenever *receiving* for appreciable periods of time.

(i) To illuminate emergency lights (top of frame B), turn on switch marked 12-V. EMERG. LIGHT, which is located to the left of the AR-8510 receiver in frame B. These lights are automatically disconnected whenever the 12-volt battery charge-discharge switch on frame C is in the CHARGE position. An auxiliary 12-volt emergency light is located in the lower section of frame C, with its own ON-OFF switch. This light should normally be kept off, and only used when working around the lower section of the frame, to inspect fuses or other components.

10. *Installation Adjustments.* As a general rule, it will not be necessary to make any major adjustments inside the transmitter for the average standard installation, because it has been carefully adjusted and lined up at the factory for operation on the five standard frequencies into a 4-ohm antenna.

Before making any of the internal adjustments, which are outlined in detail below, the installation man should operate the set, into the antenna, on each frequency, and observe the reading of the cathode ammeter. For normal operation, with filament voltage adjusted to 10 volts, and with the antenna in resonance, the cathode meter should read approximately 175 ma. The antenna coupling condensers should be readjusted if the cathode ammeter reads more than approximately 200 ma or less than approximately 150 ma.

Warning: The voltages present inside the transmitter, when the motor generator is running, are dangerous to human life, and, therefore, *extreme caution* should be observed at all times not to reach inside the transmitter unit unless the motor generator has been shut down. Make it a rule to *always* shut down the motor generator whenever the transmitter unit is swung out on its hinges, or when inserting tubes, making adjustments, changing fuses, etc.

Refer to Figure 13-20 and the following description for an understanding of the antenna coupling arrangement:

The main antenna coupling condensers, which always remain in circuit, are two .01-μf units connected in parallel. The adjustable coupling condensers are three in number, each a .004-μf unit. These three condensers may be left out of circuit entirely for the highest coupling condition or they may be connected in various series or parallel arrangements, to lower coupling.

The following tabulation indicates the six possible arrangements (A to F) for the three .004-μf condensers. These three condensers are mounted below the antenna variometer, toward the rear, and are furnished with sufficient flexible strap connectors to permit any of the six combinations listed below to be obtained:

Condenser Arrangement	*Terminal Connections*
A—None in use	Remove all straps
B—Three in series	Strap 2 to 3 and 4 to 5
C—Two in series	Strap 2 to 5
D—One in parallel	Strap 2 to 6
E—Two in parallel	Strap 2 to 6 and 1 to 5
F—Three in parallel	Strap 1 to 5, 1 to 3, 2 to 4 and 2 to 6

Arrangement A gives highest coupling. Arrangement F gives lowest coupling. Other arrangements give intermediate values of coupling.

Any large change in antenna coupling capacitors, as compared to original factory arrangement, will require a new setting for the P.A. tank inductor iron core. To determine this, ground or disconnect the antenna with antenna transfer switch and then check minimum cathode current as follows:

(a) Ground or open antenna.
(b) Operate set on 355 and 500 kc, and record cathode current.
(c) If cathode current is less than 100 ma, no changes are required.
(d) To lower cathode current, shut down set, unlock P.A. core screw and move screw in or out a *small* amount.
(e) Operate set again, recording cathode current on 355 and 500 kc, and repeat operation 4 until best possible minimum value is obtained on both frequencies.
(f) Shut down set and lock core adjusting screw.
(g) Operate set and check all five frequencies for minimum cathode current.
(h) Connect antenna, load out set and check that cathode current does not exceed approximately 200 ma.

Each of the five oscillator inductors are carefully calibrated with crystal standards at the factory for the standard operating frequencies. Normally, these adjustments should not be disturbed. If recalibration is required, use an accurate frequency meter loosely coupled to the antenna circuit (not to oscillator), move the core in or out as required, and then lock each core. Keep antenna circuit in resonance when measuring frequency. All final frequency measurements should be made with transmitter panel in its normal vertical position.

11. *Tuning Card Record.* The installation man should fill in the tuning card on the transmitter panel for each of the five operating frequencies so that the radio operator will have a convenient record of the settings for the antenna inductance switch and the antenna variometer.

12. *Maintenance.* The oscillator and power amplifier frequency switches (geared together) and the antenna inductance switch should operate freely at all times and be kept clean around the contacts and insulation. After considerable use, if it is noted that the contacts tend to "grind," a very small amount of light grease or vaseline may be applied. A small amount of lubricant applied directly to the contacts will provide smooth action, but care must be taken not to use excessive amounts as this may result in high resistance contacts. Occasionally put two or three drops of light oil on the switch shafts where they rotate in their bearings.

The break-in relay must be kept in good adjustment so that it operates with small contact clearance and a minimum sparking. The antenna circuit contacts, single-pole double-throw, are arranged to "make" when the coil is energized, before the power circuit contacts, single-pole single-throw, close. When the coil is de-energized (key open), the power circuit contacts open first, and then the antenna contacts connect the low side of the antenna circuit to the radio receiver. This contact sequence should be carefully observed, if it is ever necessary to readjust the armature travel screw mounted between the contacts. Locknut on this screw should be kept tight.

13. *Transmitter Fusing.* The main fuse panel, which is mounted directly behind access door of frame C, contains the following fuses, from left to right:

F-501—direction finder fuse, 3 amp, 250 volt, renewable
F-502—direction finder fuse, 3 amp, 250 volt, renewable
F-503—ET-8025 alternator fuse, 3 amp, 250 volt, renewable
F-504—12-volt battery, charging fuse, 20 amp, 250 volt, renewable
F-505—12-volt battery charging fuse, 20 amp, 250 volt, renewable
F-506—AR-8651 keyer fuse, 6 amp, 250 volt, renewable
F-507—AR-8651 keyer fuse, 6 amp, 250 volt, renewable
F-508—115-volt main line fuse, 30 amp, 250 volt, renewable
F-509—115-volt main line fuse, 30 amp, 250 volt, renewable

There are three additional fuses in frame C, as follows:

F-511-512—Two 12-volt battery line fuses, 60 amp, 250 volt, renewable
F-510—One ET-8025 filament fuse, 6 amp, 250 volt, renewable (above left end of emergency motor generator).

14. *Main Line Safety Switch.* An enclosed 60-amp, 250-volt, nonfusible, main-line safety switch is mounted in the lower section of frame C. The line side of this switch connects directly to the 115-volt d-c shipboard supply. The load side of this switch is connected to the various 115-volt branch circuit fuses on the fuse panel (two 20-amp, two 6-amp and two 30-amp fuses). The pair of 6-amp auto-alarm fuses are also used to fuse the line voltmeter in the ET-8024 transmitter. The main line switch should always be opened when replacing fuses, or whenever the entire 115-volt d-c supply is to be disconnected from the complete equipment.

15. *Maintenance of 12-volt Emergency Storage Battery.* The importance of maintaining the 12-volt emergency storage battery in first class condition at all times cannot be overemphasized. It will be apparent that this 12-volt battery may, in an emergency, be the sole source of power for transmitting signals. Therefore, close attention to the following instructions should be observed.

All parts of the battery should be kept clean and dry, particularly around the terminals of each cell. A light coating of vaseline will reduce corrosion if applied to the terminal connections, namely the points where the battery connects to the external wiring and where the two 6-volt units are connected in series.

The level of electrolyte in each cell should be maintained by adding approved water so that the level is approximately one-half inch above the top of the plates. Acid should never be added to the cells. The filler caps for each cell should be kept tightly in place, except when adding water or reading gravity.

The battery should be charged as often as necessary to maintain the gravity at approximately 1.285. The battery may be considered fully charged when the specific gravity, measured at three successive 15 minute periods, remains constant. A reasonable amount of gassing, during charging, should be observed. Excessive gassing (bubbling) usually indicates overcharge.

The ET-8025 charging panel and its associated resistors use eight series connected 1.37-ohm resistors (10.96 ohms total) for the full charging rate of approximately 9 amperes. For trickle charging, two parallel-connected 100-ohm resistors (50 ohms total) are connected in series with the 10.96-ohm resistor group. This provides a trickle charging rate of approximately 1.5 amp.

It is important neither to undercharge nor to overcharge the battery. Recommended procedure is to keep the battery on trickle charge while the operator is on duty, as this will minimize the amount of heat dissipated in radio room. Battery gravity should be checked periodically and the full charging rate used whenever necessary to keep the battery in good condition. Attention of radio operators is directed to section 8.118 of F.C.C. Ship Rules regarding daily tests of emergency storage batteries for polarity and correct charging rate.

When taking gravity readings, use one cell as a "pilot" cell, selecting a second "pilot" cell every six months or so in order to equalize any small loss of electrolyte over all six cells.

Exercise great care that the battery is never accidentally discharged. Normally, keep the charge-discharge switch in the "charge" position unless the ET-8025 transmitter is to be used. This may be done without overcharging the battery, since, if charging is not required the 12 V. BAT. CHARGE CIRCUIT switch can be left in the OFF position. Always leave this switch OFF if the vessel lays up or is in drydock.

16. *Important General Operating Notes.* Whenever the hinged front panel of the ET-8025 transmitter is opened or closed, it should be firmly gripped by the handles which are provided. The weight of the transmitter is considerable and it must not be permitted to "slam" into the open (horizontal) or closed (vertical) positions. Stops on the frame will hold the unit when in the fully opened position. Always keep the panel upper clamping screws tight after closing panel.

Because the ET-8025 transmitter uses a full-wave, self-rectified circuit with a total of six tubes, for normal operation, the transmitter may also be used, in an emergency, with only three tubes as a half-wave, self-rectified circuit. The filaments of all six tubes are connected in a series-parallel arrangement. The two left-hand power amplifier filaments are connected in series with the left hand oscillator filament. Likewise, the right hand power amplifier and oscillator filaments are connected in series. If it is ever necessary to operate the transmitter with only three tubes, these three tubes should be either in the left or right section of the subpanel, viewed from front to rear. With only three tubes in use, the filament voltage should be adjusted to 10 volts, the same as for normal operation with six tubes.

Important: If erratic operation of the ET-8025 is observed, always check *all* 12-volt battery circuits. Battery current is high, and corroded or loose connections will cause abnormal voltage drop. Keep *tight and clean* the following connections:

The leads on the 12-volt battery (4 connections, easily corroded).
The leads to the bottom and top of the two 60-amp fuses.
The 60-amp renewable links *inside* the fuses (usually neglected).
The two 12-volt leads from the emergency motor generator (L1 and L2).
The leads to the START-STOP SWITCH (keep screws tight).
The leads to the CHARGE-DISCHARGE SWITCH (keep screws tight).

13-2h. RMCA Model AR-8506-B Intermediate and High-frequency Receiver (Component of 4U Radio Units)—The model AR-8506-B is a five-band intermediate- and high-frequency radio receiver designed for service aboard ships or in land stations. This receiver was approved on February 6th, 1943, by the Federal Communications Commission for compliance with subsection 8.130(b) as capable of being used and operated on board ships of the United States within the limitations regarding the radiation of energy imposed by subsection 8.130(b).

1. *Design Characteristics*—(a) Ten-tube superheterodyne circuit, low radiation, for compliance with F.C.C. subsection 8.130(b) which limits radiation to 400 micro-microwatts.

(b) Triple-stage 1700-kc intermediate-frequency amplifier.

(c) Direct-line operation from 115 or 230 volts d-c or a-c power supply, without the use of external rotary converter or vibrator units.

(d) Loud-speaker built in as integral part of receiver front panel.

(e) Dual jacks for telephone receivers (low or high impedance phones may be used).

(f) High image rejection ratio.

(g) Full-vision tuning dial, calibrated in kilocycles and megacycles, entire frequency calibration visible at all times.

(h) Electrical band spread tuning control for "sweeping" the tuning over a narrow range with a fixed setting of the main tuning control.

(i) Main tuning control with 30 to 1 gear drive.

(j) Voltage regulated oscillator tube to minimize variations in oscillator frequency with variations in ship's power supply.

(k) Audio-frequency and radio-frequency gain controls.

(l) Panel-controlled OFF-ON switches for loudspeaker, AVC, and BFO.

(m) Five-position band switch which provides selection of any one of the following frequency bands:

Band	*Frequency Range*
1	85-220 kc
2	210-550 kc
3	1.9- 5.4 mc
4	5.2- 12 mc
5	11.5- 25 mc

2. *Vacuum Tubes.* The receiver uses ten standard octal base tubes as follows:

6SG7—R-f amplifier
6SG7—Mixer
6J5—High-frequency oscillator
6SG7—First i-f amplifier
6SG7—Second i-f amplifier
6SG7—Third i-f amplifier
6SQ7—Detector-AVC—first audio
25L6GT/G—Audio output
25Z6—Rectifier
6J5—BFO

In addition, a G-10 one-watt neon regulator tube is used to provide a regulated voltage source for the high-frequency oscillator. This tube has a standard double contact bayonet candelabra base.

3. *Power Supply.* The receiver may be operated directly from 115-volt a-c or d-c supply without requiring any additional conversion apparatus. Power consumption is approximately 45 watts from a 115-volt a-c or d-c line. For operation from 230 volts a.c. or d.c., a radiomarine type RM-9 external resistor unit (325 ohms, 75 watts) is required in series with the supply line. Total power consumption for 230-volt operation is approximately 90 watts.

4. *Receiver Circuits.* The receiver uses a superheterodyne circuit having one stage of r-f amplification using a 6SG7 tube. A three-gang tuning condenser tunes the r-f mixer, and oscillator circuits simultaneously. The band switch selects the coils desired and short-circuits all other unused coils to eliminate "dead spots." The circuit arrangement is shown in Figure 13-21.

A type 6J5 tube is employed in a Hartley oscillator circuit which operates with the plate at r-f ground potential. The plate voltage of this tube is regulated and kept within very close limits, even for extreme line voltage variations, by means of the voltage regulator tube. On the high frequency bands, the oscillator circuit contains "temperature

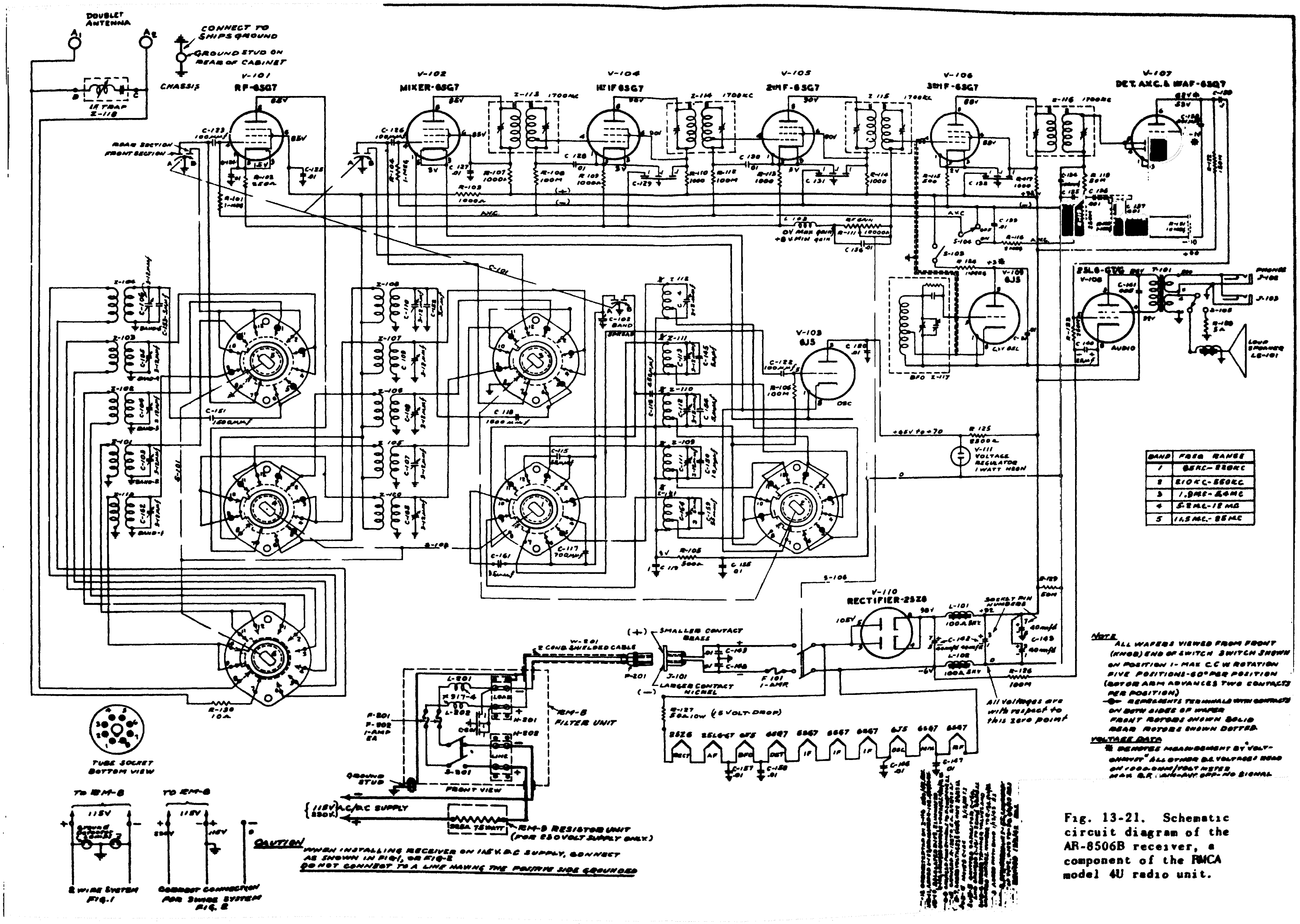
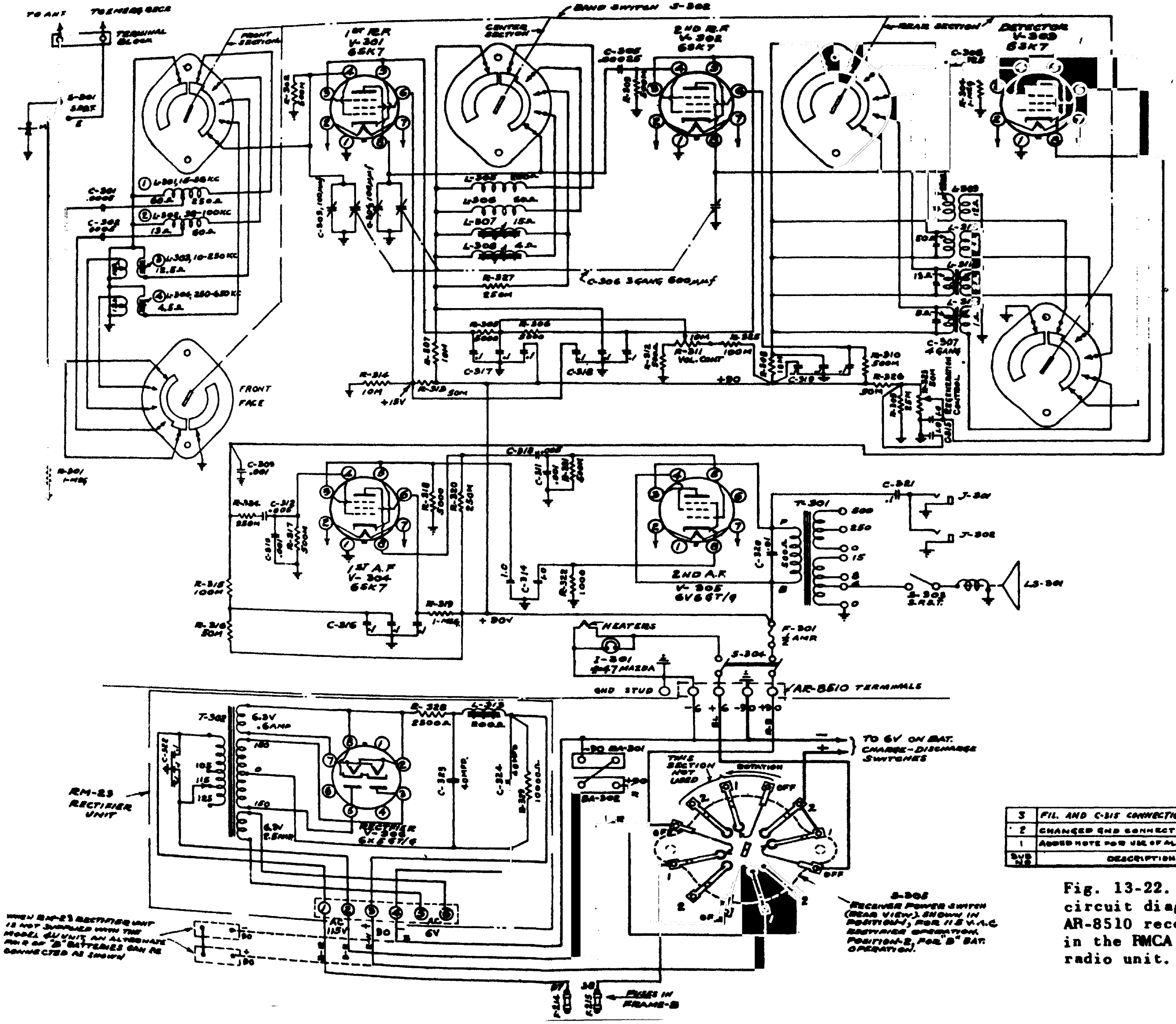

DOUBLET ANTENNA
A1
A2
CONNECT TO SHIPS GROUND
GROUND STUD ON REAR OF CABINET
CHASSIS
IF TRAP Z-118
REAR SECTION
FRONT SECTION
V-101 RF-6SG7
V-102 MIXER-6SG7
V-104 1ST IF 6SG7
V-105 2ND IF-6SG7
V-106 3RD IF-6SG7
V-107 DET. AVC. & 1ST AF-6SQ7
Z-113 1700KC
Z-114 1700KC
Z-115 1700KC
Z-116 1700KC
AVC
RF GAIN
0V MAX GAIN
+8 V MIN GAIN
V-108 6J5
CRY SEL
BFO Z-117
25L6-GTG V-108
AUDIO
T-101
PHONE J-102
J-103
LOUD SPEAKER LS-101
V-103 6J5
OSC
V-111 VOLTAGE REGULATOR 1 WATT NEON
BAND
FREQ RANGE
1 85KC-220KC
2 210KC-550KC
3 1.9MC-5.4MC
4 5.2MC-12 MC
5 11.5MC-25MC
V-110 RECTIFIER-25Z6
SOCKET PIN NUMBERS
All voltages are with respect to this zero point
(+) SMALLER CONTACT BRASS
(-) LARGER CONTACT NICKEL
W-201 2 COND. SHIELDED CABLE
P-201
J-101
F 101 1-AMP
R-127 50Ω (5 VOLT DROP)
25Z6 25L6-GT 6F5 6SG7 6SG7 6SG7 6SG7 6J5 6SG7 6SG7
RECT AF BFO DET IF IF IF OSC MIX RF
RM-6 FILTER UNIT
LOAD
LINE
FRONT VIEW
GROUND STUD
{115V / 230V} AC/DC SUPPLY
RM-5 RESISTOR UNIT (FOR 230VOLT SUPPLY ONLY)
TUBE SOCKET BOTTOM VIEW
TO RM-6
115V
2 WIRE SYSTEM FIG. 1
CORRECT CONNECTION FOR 3WIRE SYSTEM FIG. 2
CAUTION
WHEN INSTALLING RECEIVER ON 115V. D.C SUPPLY, CONNECT AS SHOWN IN FIG-1, OR FIG-2
DO NOT CONNECT TO A LINE HAVING THE POSITIVE SIDE GROUNDED
NOTE
ALL WAFERS VIEWED FROM FRONT (KNOB) END OF SWITCH SWITCH SHOWN ON POSITION 1- MAX C.C.W ROTATION FIVE POSITIONS-60° PER POSITION (ROTOR ARM ADVANCES TWO CONTACTS PER POSITION)
REPRESENTS TERMINALS WITH CONTACTS ON BOTH SIDES OF WAFER
FRONT ROTORS SHOWN SOLID
REAR ROTORS SHOWN DOTTED
VOLTAGE DATA
✻ DENOTES MEASUREMENT BY "VOLT-OHMYST" ALL OTHER D.C. VOLTAGES READ ON 1000-OHM/VOLT METER
MAX R.F. GAIN-AVC OFF-NO SIGNAL

Fig. 13-21. Schematic circuit diagram of the AR-8506B receiver, a component of the RMCA model 4U radio unit.



SUB NO	DESCRIPTION	DATE
3	FIL. AND C-315 CONNECTIONS CHANGED	2/28/44
2	CHANGED GND CONNECTION AR-8510 TERMINAL	12/6/43
1	ADDED NOTE FOR USE OF ALTERNATE "B" BATT.	7/8/43

Fig. 13-22. Schematic circuit diagram of the AR-8510 receiver used in the RMCA model 4U radio unit.

stabilized" condensers which have a negative temperature coefficient. These condensers compensate for the normal expected expansion of the other controlling components in such a way as to eliminate "drift" with large variations in temperature. As a result, the oscillator frequency and dial tuning will remain substantially fixed after a short initial warm-up period.

The 6J5 oscillator tube operates 1700 kc above the signal frequency on bands 1, 2, 3 and 4, and 1700 kc below the signal frequency on band 5. The oscillator output is mixed by the 6SG7 mixer tube.

The output from the last i-f transformer is rectified by the diode elements of the 6SQ7 tube; and the audio component, after passing through a-f gain control, is further amplified by the triode portion of this same tube and thence fed to the 25L6GT/G audio power amplifier feeding the loud-speaker and headphones. AVC voltage from the diode circuit is fed back to the preceding r.f., and the first two i-f amplifiers when the AVC switch is in the ON position. The r-f gain control regulates the amplification of the r-f, first i-f and second i-f amplifier tubes. A beat frequency oscillator consisting of a type 6J5 tube in conjunction with the BFO transformer provides a suitable beat note for CW reception.

The 25Z6 rectifier tube rectifies the incoming power when an a-c supply is connected and furnishes d.c. for the receiver plate supply. When the power supply is d.c., this tube merely conducts the plate supply voltage. The plate supply voltage is thoroughly filtered by iron-core reactors and 40-μf filter condensers for both a-c and d-c operation.

The heaters (filaments) of all tubes are connected in series, requiring a total of approximately 100 volts, the remaining 15 volts, from the 115-volt supply, being dropped through a metal clad resistor. The audio output impedance of the receiver is 4 ohms for the loud-speaker circuit and 500 ohms for the headphone jacks. Either low or high impedance headphones may be used.

5. *Operation.* Close switch on RM-8 filter unit. Turn on receiver power switch by rotating r-f gain control to the right (clockwise). Turn loud-speaker OFF-ON switch to ON position and plug in low or high impedance phones if phone reception is desired. After tubes have warmed up, advance r-f and a-f gain controls until signal or noise is received.

When tuning in a signal, it must be remembered that the dial calibration is correct when the band spread control pointer is set at its zero (center) position. This effect will be more noticeable near the upper end of each frequency band.

When standing by to receive signals, it is recommended that the AVC switch be left in the ON position, the r-f gain adjusted clockwise to a fairly high level, as determined by the prevailing noise level, and the a-f gain adjusted to produce a moderate noise output level. With these control settings, strong incoming signals will be received without "block," and at the same time, fairly weak signals, only slightly above the prevailing noise level, will also be readily received.

A greater degree of AVC control is available when the r-f gain control is most fully advanced, and a much lesser degree is available when operating with the r-f gain control in a less sensitive setting. It is also true, however, that if the r-f gain control is advanced too far "into the noise," a poor signal to noise ratio will be obtained resulting in the signals standing out less clearly above the background static. Practice in operating the receiver and observing these two effects will help in estimating the approximate control settings which will offer the best compromise and will result in the most satisfactory reception.

When receiving A1 (CW) transmissions, turn on the beat frequency oscillator (BFO) switch and adjust band spread tuning condenser for a suitable beat note. AVC may be either on or off for CW reception. It will be found that when the CW signals are very strong, a louder beat note may be obtained by reducing the r-f control setting and increasing the a-f gain correspondingly.

The various frequency bands may be selected by means of the five position band selector switch on the front panel.

When the receiver is operated from an a-c line, one side of which may be grounded, the "hum" level of the receiver may be high or low depending upon the "polarity" of the connections to the RM-8 line filter unit. Try reversing the connections of the a-c power line to the RM-8 to insure lowest "hum" level. Line polarity cannot be reversed with the power supply connector at the rear of receiver chassis, as this connector is polarized and may be inserted in one position only.

Warning: This receiver has been carefully aligned at the factory with precision instruments, and operators are cautioned *not* to disturb any of the trimmer adjustments on the chassis or on the r-f and i-f transformer cans.

Important: When AR-8506-B receiver is installed, it should be noted that band No. 2 covers the normal intermediate ship frequencies so that any frequency between 210 and 550 kc may be received. Therefore, AR-8506-B may be used for monitoring in this frequency band in lieu of the ship's regular low and intermediate frequency receiver (such as AR-8503 and AR-8510). This practice will result in a considerable increase in life of the "B" batteries usually used with the ship's low and intermediate frequency receiver. It will also be apparent that bands No. 1 and No. 2 in AR-8506-B provide "duplicate facilities" whenever reception between 85 and 550 kc is required, in the event that the ship's normal low and intermediate frequency receiver is being used on other frequencies, or is out of order.

6. *Maintenance.* Standard receiver spares comprise a complete set of tubes, 18 one amp glass fuses and a No. 20942 plug-in filter condenser. In emergency, receiver will operate with only one filter condenser if plugged in left-hand socket behind loud-speaker.

If receiver sensitivity appears lower than normal, change tubes, one tube at a time, using spare tubes, to locate any weak or defective tube. Make sure tubes are placed in sockets according to tube type numbers stamped near each socket.

If receiver appears to be "dead," check front panel fuse and the two similar fuses in RM–8 filter unit. Since all heaters are connected in series, burnout of any one heater or removal of any one tube will prevent receiver from operating. The G–10 neon regulator tube, which also serves as a pilot light, receives its voltage from the receiver plus B supply. This regulator tube will not glow until the rectifier tube has warmed up and a few seconds delay is normal when receiver is first turned on.

By referring to diagram Figure 13–21 and the circuit voltage values shown on this diagram, a high resistance multirange d-c voltmeter (1000 ohms per volt) may be used to check socket voltages, component parts and general operation if receiver performance is below normal. By disconnecting the power supply and using an ohmmeter, resistors and coils may be checked for continuity, and condensers for shorts or leakage.

When checking voltages, component parts, etc., special care should be taken not to accidentally disturb any of the trimmer adjustments. *Never* alter any of the trimmer adjustments in an attempt to "improve" receiver performance, unless the receiver is to be realigned as detailed below.

7. *Circuit Alignment.* The alignment procedure specified below must not be attempted unless an accurately calibrated test oscillator, or signal generator, and an output a-c voltmeter are available.

(a) *I-f Circuit Alignment:* If it is merely desired to check the "peaking" of the i-f system, and it is known that none of the trimmers are seriously out of alignment (such as might occur through replacement of defective transformers, etc.), this may be

R-F ALIGNMENT TABLE

Step	Connect Test Osc. to	Tune Test Osc. to	Turn Receiver Dial to	Adjust the following for Max. Output
1	A_1 through 400 ohms or I.R.E. STD. Dummy Antenna. Ground A_2	24.0 mc	24 mc—Band 5	C-114 Osc. C-110 RF (Rock Gang) C-106 Ant.
2	Same as Step 1	12.0 mc	12.0 mc—Band 5	Core Adj. Z-112
3	Repeat Step 1			
4	Same as Step 1	12.0 mc	12.0 mc—Band 4	C-113 Osc. C-109 RF C-105 Ant.
5	Same as Step 1	5.5 mc	5.5 mc—Band 4	Core Adj. Z-111
6	Repeat Step 4			
7	Same as Step 1	5.0 mc	5.0 mc—Band 3	C-112 Osc. C-108 RF C-104 Ant.
8	Same as Step 1	2.0 mc	2.0 mc—Band 3	Core Adj. Z-110
9	Repeat Step 7			
10	A_1 through 200 $\mu\mu f$ or I.R.E. STD. Dummy Antenna. *Do not Ground* A_2	500 kc	500 kc—Band 2	C-111 Osc. C-107 RF C-103 Ant.
11	Same as Step 10	220 kc	220 kc—Band 2	Core Adj. Z-109
12	Repeat Steps 10 and 11 several times if necessary until "interlocking" is negligible.			
13	Same as Step 10	200 kc	200 kc—Band 1	C-164 Osc. C-163 RF C-162 Ant.
14	Same as Step 10	85 kc	85 kc—Band 1	Core Adj. Z-121
15	Repeat Steps 13 and 14 several times if necessary until "interlocking" is negligible.			

Notes:
1. All r-f trimmer adjustments are beneath the chassis.
2. All oscillator iron-core adjustments are above the chassis.
3. Check pointer zero setting. Pointer should coincide with horizontal line at low frequency end of dial.
4. Set BAND SPREAD pointer to zero (mid-scale) position *before* proceeding with alignment.

done most conveniently by coupling a strong 1700-kc modulated signal to either terminal A_1 or A_2 and with the band switch turned to band No. 1 or band No. 2. An output voltmeter may be connected across the loud-speaker terminals or across the phones. A-f and r-f gain controls should be well advanced and enough signal fed in to give a clear output indication above the noise level. The AVC should be turned off, and it should be ascertained that the receiver is not "blocked" by too strong an input signal. Adjust both trimmers on all i-f transformers labeled 1700 kc for maximum output. In order to align the i-f wave trap, it is necessary to connect the test oscillator to terminal A_1 and to ground terminal A_2. The frequency switch must be turned to bands No. 3, No. 4 or No. 5. Adjust the iron core for minimum output. Turn on the BFO and adjust the beat note as necessary by turning the knob on top of the BFO transformer at the rear of the chassis.

If major repairs or replacements have been made to the i-f system, it may not be possible to feed a strong enough signal to the antenna terminal to obtain an output indication, and it is advisable to feed in a signal directly to the i-f grid before replacing the set in its cabinet.

(b) *R-f Circuit Alignment:* Be sure that the main tuning pointer coincides with the horizontal line on the scale when the gang condenser is closed (maximum C.C.W. rotation). If necessary, reset pointer. Set band spread control pointer to its 0 (center) position (band spread condenser one-half open). Refer to photographs for location of r-f trimmers beneath the chassis. It is necessary to remove the receiver from its cabinet when making any r-f trimming adjustments. When the receiver is operated in this manner, a connection from chassis to ground should be made.

Refer to the r-f alignment table below for details as to antenna connections, test frequencies, trimmer and iron core adjustments, etc.

When "peaking" the trimmers, two peaks will be obtained since the condensers are free to rotate 360°. Either peak may be used.

Since the intermediate frequency is high and the trimmer range is restricted, it is not possible to align incorrectly the receiver to the "image" frequency, even on the highest frequency range.

13–2i. RMCA Model AR–8510 Radio Receiver (Component of 4U Radio Unit)—The model AR–8510 radio receiver is a compact, low and intermediate frequency receiver, primarily designed for marine applications. The arrangement of the receiver is such that it may be mounted, as an integral part of the model 4U radio unit, directly below the ET–8024–A main transmitter in frame B. The receiver may also be furnished, for other applications, as an independent unit in its own cabinet.

1. *Frequency Range.* A continuous frequency range of 15 to 650 kc, divided into four bands, with ample overlap between each band, is provided. A four-position band switch permits the following bands to be quickly selected:

Band 1— 15 to 38 kc
Band 2— 38 to 100 kc
Band 3—100 to 250 kc
Band 4—250 to 650 kc

2. *Vacuum Tubes.* Five standard octal base vacuum tubes are used in the receiver as follows:

6SK7—First r-f amplifier
6SK7—Second r-f amplifier
6SK7—Regenerative detector
6SK7—First audio
6V6GT/G—Second audio

3. *Power Supply.* The receiver requires a power supply of 6 volts from a storage battery, and 90 volts from a B battery The 6-volt battery drain is approximately 1.8 amp. The 90-volt B battery drain is approximately 13 ma.

4. *Receiver Circuits.* A three-gang tuning condenser, in conjunction with individual sets of r-f coils for each frequency band, are used for tuning the two radio-frequency amplifier stages and the input circuit of the regenerative detector. The band switch is designed to short-circuit the unused coils in each stage to eliminate "dead spots," or other undesired operation. See Figure 13–22 for circuit diagram.

Separate front panel controlled trimmer condensers permit the r-f amplifier stages to be maintained in resonance when the detector input circuit is adjusted slightly off resonance for the purpose of producing an audio beat note with continuous wave reception.

The r-f gain control is connected in the cathode circuits of both r-f tubes and functions to increase the control grid negative bias when the gain is to be reduced.

The regeneration control is used to vary the voltage impressed upon the screen of the regenerative detector. This control, when advanced clockwise, causes the detector tube to regenerate, and when advanced further allows the tube to oscillate for reception of continuous waves. The cathode of the detector tube is coupled to the grid of that tube by means of individual "tickler" coils for each band.

The audio frequency component in the detector plate circuit is coupled through a resistor-condenser network to the control grid of the first audio stage. The plate circuit of the first audio tube is coupled to the control grid of the second audio tube through a resistor-condenser network. An audio output transformer, with its primary connected in the plate circuit of the second audio tube, is used. The two telephone jacks (parallel connected) are coupled to the plate end of the audio output transformer primary winding through a capacitor. This arrangement enables standard high impedance telephone receivers to be used. The 4-ohm secondary winding of the output transformer is connected, through the loud-speaker ON-OFF switch, to the voice coil of the loud-speaker. Transformer secondary taps marked "8–15" and "0–250–500" are normally not used, but are available if other output impedance taps are needed for special applications.

The battery ON-OFF switch is a double-pole single-throw unit which controls the positive 6-volt and positive 90-volt battery input circuits. A Mazda No. 47 miniature bayonet base pilot light is illuminated whenever the battery switch is turned on.

The front panel fuse (a glass fuse type 3–AG, 0.5 amp) is connected in the positive side of the 90-volt B battery circuit, and is conveniently replaced by unscrewing the bakelite cap.

The antenna switch on the front panel is a single-pole double-throw unit and is arranged to connect the incoming antenna circuit lead either to the AR–8510 receiver (main), or to a separate emergency receiver (emerg.). The emergency receiver, type C, is a separate unit of the crystal type and is described further in this book.

5. *Receiver Operation.* Place battery 1 or battery 2 on "discharge" from the battery control and charging panel. These switches are located to the right of the AR–8510 receiver in the Model 4U Radio Unit, and their functions are described further in this chapter.

Place ANTENNA SWITCH on receiver panel in position MAIN. Place RECEIVER PANEL BATTERY SWITCH in ON position. Place RECEIVER POWER SWITCH in RECTIFIER or B BATTERY position, as required.

Plug in telephone receivers, and, if desired, throw loud-speaker switch to ON position. Phones and loud-speaker may be used simultaneously or separately, as desired. Tubes will warm up in about 15 seconds.

Adjust band switch and main tuning control to desired frequency. The r-f gain control should be adjusted to a suitable position depending upon strength of incoming signal and atmospheric noise. The regeneration control should be advanced (clockwise) to the point where regeneration is optimum, or for oscillation to receive CW signals.

After the received signal has been tuned in with the main tuning knob, increased sensitivity and selectivity may be obtained by adjusting the trimmer controls on either side of the band switch, for maximum output. When this is done, it may be found desirable to reduce the r-f gain control setting for best over-all operation.

When receiving signals of a comparatively low frequency (long waves), such as bands 1 and 2, it is desirable to adjust the main tuning for a low beat note. This will provide maximum selectivity.

6. *Battery Control and Charging Panel.* The battery control and charging panel for the AR–8510 receiver comprises two small switch panels mounted at each side of the receiver in frame B of the Model 4U Radio Unit.

To the right of the receiver panel, there are two switches marked 6 V. REC. BAT. 1 DISCHARGE-CHARGE and 6 V. REC. BAT. 2 DISCHARGE-CHARGE. To the left of the receiver panel, there are also two switches. One of these switches is marked REC. BAT. CHARGE CIRCUIT OFF-ON. The second switch marked 12 V. EMERG. LIGHT—OFF-ON is used with the emergency light at the top of frame B as described under "Instructions for ET–8025 Transmitter."

The two 9-plate 6-volt storage batteries normally used with the AR–8510 receiver each has a rating of 2 amp for 35 hours and is type DLTL–9. By means of battery 1 and battery 2 charge-discharge switches, one battery may be kept on charge while the other battery is discharging through the receiver. Since the receiver drain is approximately 1.8 amp, while the battery charging rate is approximately 3 amp, both batteries may be kept in good condition by charging one of them for the same period of time that the other battery is in use with the receiver.

Approximately every two weeks both batteries may be given an equalizing charge, when the receiver is not in use, by placing both battery 1 and battery 2 switches in the "charge" position.

The function of the switch marked REC. BAT. CHRG. CIRCUIT should be understood. This switch permits the incoming 115-volt ship's line to be connected or disconnected to the 6-volt battery charging circuits. If batteries show signs of overcharging (excessive water required), the charging circuit may be disconnected by means of this switch.

The 6-volt battery charging resistors are mounted in the lower right rear section of frame B and consists of three 6-ohm, one 9-ohm and one 3-ohm resistors connected in series (30 ohms total).

When the ship lays up or is in drydock, the receiver battery charging circuit switch should be left OFF to prevent accidental discharge of the battery through the line.

7. *Receiver Maintenance.* Tubes should be replaced by loosening the front panel screws and withdrawing receiver unit. All tube sockets are plainly marked for the correct tube type.

An open 6-volt battery fuse will be disclosed by failure of the pilot light on the receiver panel to indicate. Check the four 6-amp renewable cartridge fuses on the fuse panel in the lower section of frame B.

If the filament circuit is all right and receiver inoperative, check the 90-volt B fuse on the receiver front panel. This is a glass fuse, type 3–AG, rated 0.5 amp.

The standard radio room type SLS voltmeter may be used to check receiver components. The lower shield panel at the base of the chassis should be removed for this operation.

The 6-volt and 90-volt battery voltages may be checked at their respective terminals in frame B, or, if desired, on the terminal block attached to the receiver chassis. The 90-volt B battery should be replaced if the voltage, as measured under load, is 75 volts or less (37.5 volts per 45-volt unit). In the Model 4U Radio Unit, the 90-volt B battery is mounted in a tray in the lower left section of frame B. Two 45-volt B batteries, catalog 10308 or equal, are required.

8. *Receiver Alignment.* The receiver is accurately aligned at the factory and should not be disturbed unless trimmers have been tampered with or major repairs are necessary. Alignment procedure is as follows:

Band 1: Set pointer at 38 kc. Use accurate 38-kc modulated signal and adjust No. 1 trimmer (behind tuning condenser gang) for maximum output.

Band 2: Same as band 1 except set pointer to 100 kc and peak No. 2 trimmer.

Band 3: Set pointer to 100 kc. Use 100-kc modulated signal and adjust the three 100-kc iron cores for maximum output. Then set pointer at 250 kc, use 250-kc modulated signal and adjust trimmer No. 3 for maximum.

Band 4: Same as band 3 except adjust iron cores at 250 kc and No. 4 trimmer at 650 kc.

9. *Maintenance of 6-volt Storage Batteries.* Keep the two 6-volt receiver A batteries clean and the electrolyte level one-half inch above the top of the plates. Charge one battery for the same period of time that the other battery is in use. Full charge gravity is about 1.220.

10. *RM-23 Rectifier Unit.* This unit supplies 90 volts, 15 ma for the AR-8510 receiver "B" circuit. The input is 115 volts, 60 cycles, 35 watts. This rectifier unit is mounted in the lower section of frame B on vessels where the required 115-volt, 60-cycle source is available. The rectifier tube is one 6X5GT/G. The 6.3-volt, 2.5-amp output circuit from the rectifier is not used in model 4U.

On vessels where the RM-23 is not furnished, the rectifier (RECT.) position of the RECEIVER POWER SWITCH is not to be used unless an additional 90-volt B battery has been connected as described in Section 13-2c.

When the RM-23 is installed, the operator is cautioned to always use the RECEIVER POWER SWITCH to turn the AR-8510 receiver on or off. The BATTERY SWITCH on the AR-8510 receiver panel may be left on at all times, as the RECEIVER POWER SWITCH will turn off both the rectifier and the 6-volt battery supply to the receiver. Note that the 6-volt A batteries are always used for the receiver filament supply whether or not the RM-23 rectifier unit is installed.

13-2j. RMCA Type "D" Crystal Radio Receiver (Component of 4U Radio Unit)—The type "D" radio receiver is a crystal receiver designed to meet the requirements of the Safety of Life at Sea Convention, and the Rules of the Federal Communications Commission. Such regulations require, on vessels subject to the Safety Convention, a radio receiver which is capable of receiving radiotelegraph signals, A2 or B emission, on all frequencies within the band 350 to 515 kc by means of a crystal rectifier, and for this purpose the receiver shall not require the use of electron tubes.

The circuit used in the type "D" receiver and shown in Figure 13-23 comprises a fixed inductance, a variable tuning condenser, an adjustable "cat whisker" type of crystal, a crystal by-pass condenser and phone jack.

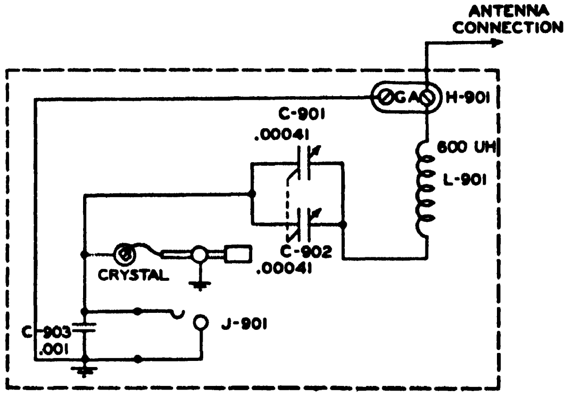


FIG. 13-23. Schematic circuit diagram of the type D, emergency crystal receiver used in the RMCA model 4U radio unit.

The receiver is adjusted by tuning the variable condenser to the desired signal and by regulating the cat whisker to a sensitive spot on the crystal.

When used with the type AR-8510 main and emergency vacuum tube receiver, the AR-8510 includes an antenna transfer switch for connecting antenna circuits to the input of the type "D" crystal receiver.

The type "D" receiver is mounted on a panel in frame D of the Model 4U Radio Unit to the right of the AR-8506-B receiver.

13-2k. RMCA Model AR-8601 Auto Alarm (Component of 4U Radio Unit)—The radio marine model AR-8601 auto alarm has been designed to meet the following requirements:

International Telecommunications Conferences Cairo 1938.

Federal Communications Commission "Auto Alarm Requirements and Type Tests, October 1, 1935" (mimeograph publication No. 14247), and F.C.C. Rule 8.130(b).

The AR-8601 also complies with the technical requirements of Federal Communications Commission order No. 28 and order No. 28A with respect to energizing the audible alarms when the 6-volt battery decreases to 4 volts, or fails altogether, at the point where the battery circuits enters the auto alarm unit, and also to energize the audible alarms when the voltage of the 110-volt direct-current power supply decreases to 90 volts or less.

The fundamental purpose of the auto alarm is to stand a watch on the 500-kc distress frequency at all times when the radio operator is not on duty. The International Auto Alarm Signal consists of a series of dashes four seconds in length, separated by spaces having a duration of one second. Twelve such dashes and spaces can be transmitted in one minute. Auto alarms designed to meet the requirements of the Federal Communications Commission are arranged to actuate warning bells when four correct dashes and spaces have been received.

It should be clearly understood that the primary function of the auto alarm is to *receive* signals in cases of distress. The transmission of such signals *from* the vessel in distress (or sometimes by shore stations for distressed vessels) is accomplished by using a radio room clock with a sweep second hand, or by means of an automatic alarm signal keying device. The radio room clock is designed with suitable marking on its dial to facilitate transmission of the correct dashes and spaces, this clock also being used by the radio operator when he tests the auto alarm before going off watch. This point is covered in detail further in this chapter.

1. *Component Units.* The principal component units of the model AR-8601 auto alarm are housed in a single, copper-plated steel frame, known as frame A. While the assembly in frame A may be installed as an independent unit, it is also designed for application as an integral part of a complete model 4U Radio Unit.

External to the radio room there is installed an alarm bell and warning light unit on the bridge, a bell unit in the radio operator's quarters, and a 6-volt 9-plate storage battery in an adjacent battery room.

The standard spare parts furnished with each model AR-8601 auto alarm are listed separately in this chapter.

2. *Power Supply Requirements.* The main power supply for the AR-8601 auto alarm is the shipboard 115-volt d-c line. A current of approximately 1.5 amp is required. This 115-volt supply is used for all filament circuits, plate circuits, screen circuits, oven heater and charging circuits of the auto alarm. A 6-volt storage battery is also used. This battery furnishes energy for ringing the alarm bells and for energizing the stepping relay and auxiliary relay in the auto alarm. The normal current required from the 6-volt battery is .4 amp, except when all alarm bells are ringing when a current of approximately 3 amp is required.

3. *Description of Over-all Assembly.* The AUTO ALARM MASTER SWITCH is a three-position switch located in the top of frame A in model 4U Radio Unit. The circuit functions are as follows:

(a) Position 1. Alarm on. Battery discharging.
Main antenna is connected to auto alarm receiver input circuit.
115-volt d-c ship's line is connected to alarm.
6-volt storage battery is connected to alarm.

(b) Position 2. Alarm off. Battery off. (Transmitting position—Emergency antenna.)
Emergency antenna is connected to TRANSMITTER SELECTOR SWITCH.
115-volt d-c ship's line is disconnected from alarm.
6-volt storage battery is disconnected from alarm.

(c) Position 3. Alarm off. Battery charging. (Transmitting position—Main antenna.)
Main antenna is connected to TRANSMITTER SELECTOR SWITCH.
115-volt d-c ship's line is disconnected from alarm.
6-volt storage battery is disconnected from alarm.

The over-all design of the master switch is such that the alarm cannot be turned on unless it is connected directly to the main antenna, irrespective of any other equipment in the radio room. To protect the auto alarm receiver from excessive voltages, a static leak and adjustable spark gap (1/32") are provided on the master switch. Key interlock circuits are not used or required with the master switch as used in the Model 4U Radio Unit. This is because the antenna circuits (from the transmitter selector switch) are completely disconnected from the auto alarm when the master switch is in position 2 or 3.

The radio receiver-selector unit is constructed on a hinged front panel so that it may swing forward to a horizontal position for adjustment or maintenance.

A vertical sub-panel at right angles to the front panel is provided inside the unit on which are mounted the radio receiver and selector components.

Five radio frequency transformer units are mounted in a row along the upper section of the sub-panel. Each of these units is constructed with impregnated Litz coils and air dielectric tuning condensers. The coupling between the various r-f coils is adjusted at the factory to secure the specified bandwidth and selectivity. The first transformer unit behind the front panel contains the 1600-kc r-f oscillator circuits. The next unit, toward the rear, is the 500-kc input transformer. The next three units are the 1100-kc intermediate-frequency transformers.

Nine vacuum tubes are used in the receiver-selector. All tube sockets are plainly marked for the correct tube type. The arrangement of tubes is as follows:

Top row, viewed from front panel toward rear

One 6A8—mixer-oscillator tube
One 6K7—first intermediate amplifier tube

One 6K7—second intermediate amplifier tube
One 6H6—diode detector tube

Bottom row, viewed from front panel toward rear
One 1611—voltage regulator tube
One 1611—radio relay tube
One 1611—first selector tube
One 1611—second selector tube
One 1611—third selector tube

There are three selector relays, mounted in a thermostatically controlled oven, which is located directly beneath the tubes. A suitable heater and bimetallic thermostat are used inside this oven to maintain a temperature of 55° C. The heater in this oven, which is controlled by the thermostat, is permanently connected to the 115-volt ship's line, and operates at all times whether or not the auto alarm is in use. The heat from this oven is also used to maintain the various component units of the receiver-selector dry under marine conditions.

The stepping relay is located at the rear of the oven. This relay advances one position each time a correct dash and space are received. When the stepping relay reaches the fourth position, after four correct dashes and spaces, the warning bells are energized.

There are four relays mounted beneath the oven. The first relay, viewed from the rear of the front panel, is the radio relay which is actuated by incoming signals, as explained further in this book. The next relay is the filament burnout relay, which is used to ring the warning bells in case the filaments of any vacuum tubes should burn out. The next relay is the bell ringing relay which closes upon receipt of an alarm signal, and remains closed causing the bells to ring continuously until the reset button is depressed. The fourth relay (underneath stepping relay) is known as the auxiliary relay and its function is explained further in this text.

Various resistors, condensers, filter chokes and filter reactors are mounted on the sub-panel of the receiver-selector unit. All of these components are mounted to permit convenient checking or maintenance.

4. *Arrangement of Front Panel.* The front panel of the receiver-selector unit contains the following controls and instruments:

(1) A 0–15 ma, d-c milliammeter, together with a five-position "current" switch. The functions of this switch when used with the milliammeter are as follows:

Position 1—Selector tube 1 plate current
Position 2—Selector tube 2 plate current
Position 3—Selector tube 3 plate current
Position 4—Signal relay tube plate current
Position 5—Not used

(2) A 0–150 volt, d-c voltmeter, together with a five-position "voltage" switch. The functions of this switch when used with the voltmeter are as follows:

Position 1—Voltage regulator tube output voltage
Position 2—Selector tubes 1 and 2 grid bias voltage
Position 3—Selector tube 3 grid bias voltage
Position 4—Tube heater voltage
Position 5—Ship's line voltage (less drop in r-f filter chokes)

Also mounted on the front panel are the following:

(3) A sensitivity control for adjusting the amplification of the radio receiver.

(4) A 0.5-amp glass fuse (plate circuits).

(5) An amber pilot light which indicates ON-OFF operation of the thermostat in the oven.

(6) A red pilot light to indiciate when the stepping relay has advanced from its "zero" position.

(7) A jack for plugging in telephone receivers so that incoming signals may be monitored.

(8) A test buzzer to provide a local signal for testing over-all operation of the alarm.

(9) A "Bridge" push button to temporarily disconnect the bridge and operator's room bells during testing.

(10) A "Test" push button to actuate the buzzer.

(11) A "Reset" push button to stop all bells from ringing.

(12) An instruction card entitled "Adjustments to Be Made by Radio Operator Before Going Off Watch."

5. *Construction of Power Panel.* A power panel is mounted in the lower section of frame A. A hinged door provides access to the various units mounted on the power panel. The following units comprise the power panel assembly:

(1) A fuse block for two 6-amp, 250-volt, renewable cartridge fuses (115 volt d.c.).

(2) Fuse blocks for two 10-amp, 250-volt, renewable cartridge fuses and one 6-amp glass fuse, these three fuses being connected in the 6-volt storage battery circuits.

(3) A 9-volt C battery which provides bias for the voltage regulator tube.

(4) A pair of dual radio-frequency choke coils which filter the incoming 115-volt d-c line supply circuits.

(5) A 6-volt battery relay arranged to close its contacts if the battery voltage falls below approximately 4.5 volts, thereby ringing the warning bells.

(6) A line voltage relay whose contacts short out the coil on the 6-volt relay, causing the warning bells to ring in the event that the shipboard line voltage falls below approximately 90 volts or is increased to approximately 130 volts.

(7) Two 100-ohm, ferrule type, charging resistors connected in parallel, for charging the 6-volt storage battery.

(8) Two 80-ohm filament resistors, one connected in series with all tube heaters, and the other connected in parallel to the tube heaters having 0.3-amp rating. Since the type 1611 tubes have a heater current of 0.7 amp, the 80-ohm paralleling resistor passes 0.4 amp to compensate for the 0.3 amp required by the 6A8, 6K7 and 6H6 tubes.

(9) A terminal block for all incoming wiring.

(10) A radio room warning bell.

6. *Bridge Bell and Warning Light Unit (RM-25).* The bridge bell and warning light unit comprises a metal box in which is mounted the warning bell and a 6-volt Mazda No. 47 warning light. This unit should be installed on the bridge in a location to permit viewing by the officer on watch. A slotted cover for the warning light restricts undesirable illumination from this light.

7. *Operator's Room Bell Unit (RM-26).* This unit is similar to that furnished for installation on the bridge, except that it does not contain a warning light.

8. *Operation of Radio Receiver-Selector Unit.* The radio receiver circuits of the auto alarm utilize a five-tube superheterodyne circuit which is shown in Figure 13-24.

The antenna circuit after passing through the master switch and a 500-ohm resistor connects to a tuned trap circuit (mounted back of the panel), which is adjusted at the factory for a frequency of 1100 kc. This is the intermediate frequency of the receiver and the trap circuit is provided to suppress interfering signals having a frequency of 1100 kc. The 500-ohm resistor is furnished to act as a limiter and to destroy antenna circuit resonance so that the receiver complies with Federal Communications Commission Rules with respect to radiation. After passing through the trap circuit, the incoming signal is connected through a small condenser (50 $\mu\mu$f) to a pair of broadly tuned circuits, which are adjusted to respond to 500 kc plus or minus 12.5 kc. In other words, signals having a frequency from 487.5 to 512.5 kc are accepted. The first tube in the radio receiver is a type 6A8 mixer-oscillator. The oscillator portion of this tube is connected to a circuit which oscillates at a frequency of 1600 kc. This 1600-kc energy is mixed with the incoming 500-kc signal, and produces in the plate circuit of the 6A8 the intermediate frequency of 1100 kc.

The 6A8 mixer-oscillator tube is followed by two stages of intermediate-frequency amplification, each stage using a 6K7 pentode amplifier tube. The intermediate amplifier uses a total of six tuned circuits which are so coupled to enable the incoming signal to vary between 487.5 and 512.5 kc, without attenuation.

The fourth tube in the radio receiver is a type 6H6 diode detector. This tube has two plates which are connected in parallel and two cathodes which are connected in parallel. The radio signal, now at intermediate frequency, is rectified in the 6H6 detector stage and produces a d-c voltage which appears across a one-megohm resistor connected between the cathodes and one side of the third i-f transformer secondary. This d-c voltage from the diode stage is applied as a negative voltage to the grid of the fifth tube in the receiver, type 1611, which is known as the radio relay tube. The relay tube has connected in its plate circuit the coil of the radio relay. Any incoming signal between 500 and 90,000 microvolts, and within the specified frequency band, will actuate the armature of the radio relay. The type 1611 relay tube, in the absence of signals, has a steady current (about 9 ma) flowing through its plate circuit. This current is reduced upon the receipt of a signal. This relay then initiates the timing action of the selector tubes in a manner to be described below.

An auto alarm selector to operate efficiently with the International Alarm Signal, and to reject interfering signals, must perform three main functions. It should reject signals having a duration less than approximately 3.5 seconds. It should reject signals having a duration greater than 4.5 seconds. It should also be designed to recognize spaces between signals provided these spaces do not exceed 1.5 seconds. In the model AR-8601 auto alarm three selector tubes, with appropriate relays, are used.

As pointed out above, correct incoming signals will lower the plate current of the 1611 relay tube, causing the armature to make a contact. This applies a positive voltage to the grid of number 1 selector tube, type 1611, through a suitable resistance capacity network. This network causes a time delay so that no plate current will flow in the number 1 selector tube plate circuit until approximately 3.5 seconds have elapsed. At the end of this time the plate current of selector tube number 1 energizes the coil of the first selector relay and closes its contacts. These contacts then energize the "notch" coil of a stepping relay, which advances this latter relay one position. At the same time that the "notch" coil on the stepping relay is energized, voltage is also applied to the coil of the auxiliary relay. One pair of contacts on this auxiliary relay energizes the grid of the second selector tube, type 1611, which also uses a resistance capacity network in its grid circuit. If the incoming signal lasts for more than 4.5 seconds, current will flow in the plate circuit of the second selector tube and will energize selector relay number 2. This, in turn, will cause contacts to close on selector relay number 2, which will energize the "restore" coil on the stepping relay. When the signal ceases, under these conditions, the stepping relay returns to its zero or starting position.

From the foregoing it may be seen that signals having a duration between, 3.5 and 4.5 seconds will cause the stepping relay to advance one position. It is now necessary to provide means for checking that the spaces between dashes are not excessive.

This is accomplished by means of the third selector tube, type 1611, and the third selector relay. The contacts on selector relay number 3 also energize the "restore" coil of the stepping relay. Spaces are checked as follows. At the end of any dash lasting between 3.5 and 4.5 seconds, the auxiliary relay coil is de-energized and a pair of back contacts apply voltage to the grid of selector tube number 3 through a resistance capacity network. After a time interval (approximately 5 seconds) plate current begins to build up in selector tube number 3. However, if any subsequent dash after the first one is completed within 3.5 seconds, the auxiliary relay closes again de-energizing selector tube number 3. If the second or subsequent dashes are not completed in time, selector relay number 3 closes, energizing the "restore" coil on the stepping relay.

The above explanation of selector operation may be somewhat difficult to understand at the first reading. However, if the auto alarm is operated with the test buzzer and the action of the various relays observed, as explained further in this chapter, it is possible to secure a clear understanding of the over-all operation.

A voltage regulator tube, type 1611, is used in the auto alarm. The purpose of this tube is to supply a regulated source of voltage for the grid circuits of the three selector tubes. Constants of the voltage regulator circuit are so designed to permit a small change in grid voltage to take place on the selector tubes, under conditions of changing line voltage, so that timing of the selector circuits is not impaired.

The warning lights are used to indicate when heavy static or other interference impairs operation. Each time the stepping relay advances one position, a circuit is closed to the warning lights. These lights will remain lighted unless the static decreases or until a new adjustment is made on the sensitivity control.

9. *Adjustments to Be Made by Radio Operator Before Going Off Watch.* On the front cover of the auto alarm there will be found printed instructions which read as follows:

IMPORTANT INSTRUCTIONS

"*To Test Alarm:* Close master switch. Set sensitivity control to approximately 40. Using radio room clock transmit alarm signal with test push button on auto alarm. Bell will ring after four correct dashes and spaces. See instruction book for further details."

"*To Adjust Sensitivity Control:* Set scale at 0. Set current switch at 4. Meter will read about 9 ma. Turn sensitivity control to right until average meter reading, due to noise, static, etc., is about 1 ma less than the maximum value. Listen with phones. Incoming signals will cause signal relay to chatter slightly and meter reading to fall toward zero. If sensitivity is set too high for prevailing noise level, warning lights will indicate need for lower setting. Do not set sensitivity control lower than necessary as weak distress calls may not be received."

When testing the auto alarm with the test buzzer and push button, the operator should observe that the milliammeter reading falls to zero, or nearly so, each time the test button is depressed. Close this button quickly several times and observe that the radio relay, whose armature click may be heard, follows the keying speed. Each time a correct four second dash and space are sent with the test buzzer, it may be observed that the stepping relay advances one position. If there is considerable radio interference or static during the time the alarm is being tested, it will be observed that the "restore" coil on the stepping relay is also energized, thereby preventing the stepping relay from advancing further. This condition will occur during testing whenever static or interference completely fills the spaces between dashes so that the normal auto alarm signal is distorted. The position of the sensitivity control, during the test of the auto alarm, may be used as an approximate check on the sensitivity of the receiver and the correct performance of all tubes. If it is found necessary to advance the sensitivity control beyond approximately 40 to 50 on the scale, it may be inferred that one of the tubes in the radio receiver part of the circuit is defective. After a little experience with the alarm, using the headphones plugged into the jack and by observing the operation of the radio relay on incoming signals, the operator may reach an approximate determination as to whether or not the receiver sensitivity is normal. In other words, on the average shipboard antenna, it should not be necessary to advance the sensitivity control to the extreme right in order to make the radio relay operate with the average incoming signal.

10. *Sensitivity Control Adjustment.* A clear understanding of the results to be expected from various settings of the sensitivity control is necessary in order to adjust this control to the optimum or most favorable position. For example, if the sensitivity control is turned to the extreme right (100 on the dial), or nearly so, it may be found that the average noise level and static will cause the radio relay to hold over for long periods of time, or to chatter or vibrate steadily. When this occurs, the adjustment is not a favorable one, for not only will the warning light be illuminated frequently, whenever static or noise persists for 3.5 seconds or more, but also a real alarm signal will be more apt to have its dashes prolonged and its spaces filled in, with such an adjustment. On the other hand, if the sensitivity control is adjusted too far to the left, that is toward zero on the scale, then only very strong signals will operate the auto alarm, and a distress call from a distant ship might be missed. The optimum adjustment will be found

to be that which gives a reading on the milliammeter (with no incoming signals) which is approximately one milliampere less than the reading obtained when the volume control is at zero. With such an optimum adjustment, the radio relay may close occasionally from short bursts of static or from ordinary code signals. The operator should keep in mind that if the sensitivity control is set too high the radio relay will vibrate constantly, which is an undesirable adjustment. The officers on the bridge will have instructions to summon the radio operator whenever the warning light on the bridge is illuminated for periods of five minutes or more. When the sensitivity is set at 100 or maximum, a signal strength of approximately 200 microvolts will operate the auto alarm. At a dial setting of 50 (mid-scale), a signal of approximately 1000 microvolts is required. At 0 setting of the sensitivity control, a signal strength of 20,000 microvolts is required.

11. *Faults Which Will Cause Sounding of the Alarm Bells.*

(a) False alarm. Accidental static or other interference may occasionally cause the stepping relay to advance to its fourth position, which will lock in the bell ringing relay and cause the bells to ring continuously. Bells will stop when reset push button is depressed on auto alarm panel.

(b) Filament burnout. If any one of the vacuum tube filaments (heaters) should burn out, or if the 80-ohm series filament resistor in the power panel should burn out, the filament burnout relay on the auto alarm panel will have its coil de-energized, which will close the back contacts, and cause the bells to ring. Bells can only be stopped from ringing by replacing the defective tube, or resistor or by opening the master switch.

(c) Low or high line supply voltage. If the 115-volt shipboard supply is reduced to 90 volts, or increased to 130 volts, the line voltage relay in the power panel will operate, which will short out the coil on the 6-volt relay, causing the bells to ring. The bells will continue ringing until line voltage is restored to normal or until master switch is opened.

(d) If the 6-volt battery approaches discharge and its voltage falls below about 4.5 volts, the back contacts will close on the 6-volt relay, causing the bells to ring continuously until a suitably charged battery is placed in circuit, or until the master switch is opened.

(e) If the 0.5-amp glass fuse on the front panel should blow, or if the 6-amp glass fuse on the power panel should blow, the bells will ring continuously until the fault is corrected, or until the master switch is opened. The 0.5-amp glass fuse will blow in case of tube shorts or condenser breakdowns in the receiver-selector unit. The 6-amp glass fuse will blow in the event of shorts in the 6-volt wiring inside power panel, or receiver-selector circuits. It should be noted, however, that blowing of either of the 10-amp, 250-volt, renewable fuses in the 6-volt storage battery circuit will not actuate the warning bells, because these fuses are connected directly to the incoming battery circuit. It is for this reason that the separate 6-amp glass fuse is provided, as normal internal circuit protection, since this fuse will blow before the 10-amp renewable fuse.

12. *Operation of Warning Lights.* The purpose of the warning lights as explained previously is to provide a visual indication whenever prolonged static or other interference holds the radio relay open. After 3.5 seconds, the stepping relay will advance one position and remain there as long as the interference is continuous. An auxiliary set of contacts on the stepping relay will close a circuit to the two warning lights to indicate this condition. The remedy is to readjust the sensitivity control to a slightly lower setting so that the stepping relay drops back to its normal or zero position.

13. *Procedure to Be Followed When Alarm Bells Ring.*

(a) If alarm bells ring momentarily, then stop ringing, and repeat this cycle frequently, the difficulty is most likely due to low, high or variable line voltage. Go to the radio room, open the lower door and observe the line voltage relay contacts. Also measure the line voltage by placing the voltmeter switch in position five on the auto alarm panel. If the voltage is below approximately 90 volts, it will be observed that the line voltage relay "left" contact is closed, causing the bells to ring. High line voltage (approximately 130 volts) will cause the "right" contact to make on the relay, also ringing the bells. This condition of low, variable, or high line voltage should be brought to the attention of the proper ship's officer.

(b) Alarm bells ringing continuously. Go to the radio room and depress the reset button on the auto alarm. If this stops the bells from ringing, a pair of phones should be immediately plugged into the phone jack to determine if an alarm signal has been transmitted by a vessel in distress. If the bells do not stop ringing when the rest button is depressed, the fault may be low line voltage, high line voltage, low 6-volt battery supply, filament burnout, or blown fuses. Filament burnout may be immediately determined by placing the voltmeter switch in position four, where a reading of 100 volts or more will be obtained instead of the normal reading of approximately 60 volts. A blown one-half ampere plate fuse or 115-volt line fuse (6 amp) may be quickly determined by observing if any reading is obtained on the voltmeter with the switch in position five. No reading will be obtained if these fuses are blown. If the 6-volt battery is low, this should be checked with the three scale voltmeter carried in the radio room as a part of standard safety of life at sea equipment.

(c) When troubles which cause the bells to ring continuously cannot be located quickly, it is desirable to disconnect the bridge bell and operator's bell temporarily to avoid undue annoyance to the ship's personnel. This may be done by removing the leads which will be found on terminals 32 and 34 of the power panel. After the trouble has been corrected, the operator should make certain that the leads to terminals 32 and 34 are firmly reconnected, and he should make a test with the bridge and the operator's room to insure that the bells are again functioning normally.

14. *Log Entries.* The following instructions with regard to log entries are furnished for the convenience of the operator, and are not intended to supersede or supplant the official instructions issued by the Federal Communications Commission. The latest rules and regulations of the Federal Communications Commission "Part 8—Rules Governing Ship Service" should be carefully studied by operators:

(a) While the ship is navigating outside a harbor, or port, the auto alarm should be tested at least once every 24 hours by means of the test buzzer, the timing of the dashes and spaces being made by referring to the second hand of the radio room clock. A test should also be made to determine that the auto alarm, as a whole, is operating in a normal manner when receiving signals on 500 kc from other stations. A statement that these tests have been made should be inserted daily in the radio station log.

(b) Adequate records should be maintained on Federal Communications Commission's form 819, covering operation of the auto alarm.

(c) Each time the auto alarm is placed in operation, a log entry should be made of the date and time, the sensitivity control setting, and the minimum number of four second dashes from the test buzzer which were necessary to properly operate the alarm. A log entry should also be made of the time when the auto alarm is taken out of operation.

(d) A log entry should be made whenever the warning light on the bridge remains actuated for a continuous period of five minutes, including particulars as to the time the operator was called to make the necessary repairs or adjustments, any reason for the failure, the names of any parts removed, added or substituted, repairs affected, and the time the alarm was restored to proper operating condition.

(e) A log entry shall also be made whenever the auto alarm becomes inoperative due to causes not indicated by the warning light or the bells, or whenever the bells are actuated. This entry shall include a statement showing the time the operator was called to make any necessary repairs or adjustments, the reasons for the warning bell being actuated, or failing to be actuated, any parts removed, added or substituted, repairs affected, and the time the auto alarm was restored to proper operating condition.

15. *General Maintenance and Repairs at Sea.* If normal operation of the auto alarm cannot be obtained, the radio operator should proceed as follows:

Important: Do not remove relay cover or oven cover on the auto alarm panel, or work with tools around any of the parts unless the master switch is in the "off" position.

(a) Check with three-range radio room voltmeter to determine if the 115-volt line voltage and 6-volt battery power exists across the appropriate input terminals on the power panel. If correct readings are obtained, make similar measurements across the proper terminals of the receiver-selector unit.

(b) Make certain that all leads on the terminal blocks are tight and making good connections.

(c) Relay contacts should be checked and cleaned, if necessary, to insure proper contact. To clean contacts use the special burnishing tool which is furnished, taking care not to remove too much contact material with the burnisher.

(d) If defective tubes are suspected, they should be replaced one at a time, starting with the 6A8 tube, always returning good tubes to the same socket from which they were removed. This will avoid confusion in locating a defective tube. Type 1611 tubes may be checked for emission by placing them successively in the second socket from the left in the lower row of tubes. This is the radio relay tube socket and the plate current of this tube may be read by the milliammeter with the switch in position number four. Normal tubes with 115 volts line should show a plate current with no incoming signal of approximately 9 ma. When checking tubes all tube sockets must be filled, otherwise bells will ring.

(e) Each selector circuit may be checked by sending a test signal through the auto alarm and successively placing the "current" switch in position 1, 2 and 3. In position 1, after a long dash, a current of approximately 8 to 10 ma will be obtained. In position 2, after a long dash, a similar value will be obtained. To check selector number 3, place the switch in position 3, send a 4-second dash with the test buzzer, and then observe after about 5 seconds that the meter reads momentarily a value of approximately 6 ma. The third selector tube shuts off its own plate current after it checks a space and for this reason only a momentary meter reading will be obtained.

(f) It is possible to check various voltages on the power panel and on the various component units back of the auto alarm panel by referring to circuit diagram, and by using the three-range voltmeter which is carried in the radio room. Such a voltage analysis will enable the operator to determine if open circuits or poor connections exist in various parts of the circuits.

(g) The switch contacts on the master switch should be checked occasionally to insure that they are making good connection, removing any corrosion or oxidation which may have taken place.

(h) Normal operation of the oven heater will be indicated by intermittent operation of the amber pilot light. This pilot light is provided to enable the radio operator to determine that the oven circuit is operating normally whether or not the auto alarm is on watch.

(i) If for any reason the auto alarm 6-volt battery becomes discharged the operator should substitute one of the radio room 6-volt storage batteries temporarily. The auto alarm battery should then be placed on charge from the standard radio room "A" battery charger. The auto alarm master switch is arranged to place the 6-volt battery on charge at a rate of approximately 2 amp whenever the master switch is in position 3. This charging rate is sufficient to keep the alarm battery fully charged if the alarm is "on watch" for a period of 18 hours daily. In other words, 6 hours charging in each 24 hours will keep the battery in good condition. If either battery charging resistor should become defective, replace it with the spare 100 ohm unit that is furnished.

(j) When replacing the 9-volt "C" battery, make certain that the green lead connects to the positive terminal and the yel-black lead to the positive terminal. No current is taken by the "C" battery; therefore, if early "C" battery replacement is necessary, look for shorts or leakage. A voltmeter connected in series with one of the "C" battery leads should show no reading for normal operation.

(k) If plate current is obtained through each selector relay as explained under (e) above, and the stepping relay does not operate, inspect the contacts on the selector relays in the oven. Remove oven cover screws and carefully withdraw the oven cover straight out to prevent breakage of the thermometer. Relay contacts may now be examined and cleaned if necessary. (Temporary removal of right-hand stay hinge is necessary for this operation.)

(l) Note that the 6-volt storage battery has two fuses in the positive side of the circuit, a 6-amp glass fuse and also a 10-amp renewable fuse. Short circuits in the 6-volt circuits in the auto alarm will normally cause the 6-amp glass fuse to blow. This arrangement allows the warning bells to ring when the 6-amp fuse is blown. All three battery fuses should be inspected in case of trouble. Always use the specified rating when replacing fuses.

(m) The line voltage relay will also cause the bells to ring if the polarity of the 115-volt shipboard line is reversed. The voltmeter on the receiver-selector unit in switch position 5 will also indicate this condition by reading in the reverse direction.

16. *Typical Readings of Current and Voltage for Normal Auto Alarm Operation.* The following readings are based on an average line voltage of 115 volts. Other line voltages will give slightly different readings.

Current Switch:

Position 1—First selector relay closes at approximately 4 to 6 ma.

Position 2—Second selector relay closes at approximately 5 to 7 ma.

Position 3—Third selector relay closes momentarily at approximately 5 to 7 ma.

Position 4—Signal relay plate current is approximately 9 ma with no incoming signal. With signals, lower values, down to zero, will be obtained.

Position 5—Not used.

Voltmeter Switch:

Position 1—Voltage regulator tube output 57 volts.

Position 2—Grid bias on selector tubes 1 and 2, 34 volts (approx.).

Position 3—Grid bias on third selector tube, 34 volts (approx.).

Position 4—Heater voltage 60 volts.

Position 5—Reads ship's line voltage (less 2 volts drop in r-f filter chokes).

When going off watch the operator should always leave the "current" switch in position 1 and the "voltage" switch in position 5. If the current switch is left in position 4, the milliammeter will follow all incoming signals, causing unnecessary wear and tear on the instrument.

17. *Testing Auto Alarm Under Severe Static Conditions.* Occasionally when static is very severe the sensitivity control cannot be advanced far enough to permit the test buzzer to acutate the receiver without causing the radio relay to "block" from the static. To test the alarm under these conditions, place a temporary short circuit between the antenna terminal and ground. After the test, the short circuit should be removed and the sensitivity control adjusted to optimum for the prevailing noise level.

18. *Understanding Selector Action by Observing Relays.*

(a) Transmit "V"s or other code signals with test buzzer. Radio relay will follow keying and milliammeter in position 4 will show a lower reading each time buzzer is operated. No other relays will operate.

(b) Transmit one four second dash. Radio relay will operate instantly and after 3.5 seconds number 1 selector relay in oven will close, auxiliary relay will close, "notch" coil will be energized and stepping relay will advance one position. This checks if dash is long enough.

(c) Transmit one dash of 5 seconds or more. Same action as under (b) above will take place, and in addition number two selector relay in oven will close and "restore" coil on stepping relay will be energized. When long dash is broken, stepping relay will return to zero or normal position. This checks overlong dashes.

(d) Transmit one four second dash to advance stepping relay one position and then break this dash. After approximately 5 seconds, "restore" coil will click and stepping relay will return to zero. This checks spaces.

(e) Transmit four correct 4-second dashes separated by 1-second spaces and watch the stepping relay move up with each dash, finally causing the bell ringing relay to lock in when the fourth dash is broken. Note that each dash, including the fourth dash must be followed by a space to lock in the bell ringing relay. If the fourth dash (or any other dash) is too long, the "restore" coil is energized on the stepping relay.

13–21. RMCA Model AR–8651 Alarm Signal Keyer (Component of 4U Radio Unit)—These instructions cover the description, operation, and maintenance of the Radiomarine model AR–8651 alarm signal keyer.

1. *Description.* The AR–8651 alarm signal keyer is designed primarily for use in the radio room of passenger or cargo vessels for the purpose of automatically "keying" radiotelegraph transmitters with the International Automatic Alarm Signal. This alarm signal, fundamentally, consists of a series of dashes and spaces, each dash having a duration of four seconds, while the spaces between each dash have a duration of one second. Therefore, it may be said that the basic alarm signal "cycle" has an overall duration of five seconds, since it consists of a four-second dash and a one-second space.

Present day automatic alarm receivers (not to be confused with the alarm signal keyer covered here) are designed to actuate warning bells after correctly receiving four alarm signal "cycles." Some foreign vessels use three "cycle" alarm receivers. However, to allow for the effects of static, interference, etc., the Alarm Signal should be transmitted for a period of at least 60 seconds (12 cycles). If necessary, the alarm signal may be transmitted for longer periods in order to summon aid, with due regard on the part of the radio operator to *listen* after transmitting each 60-second group of signals.

In the past, customary procedure for "timing" the alarm signal has been by means of manual operation wherein the radio operator closes and opens the normal telegraph key by referring to a sweep second hand clock in order to transmit four second dashes and one second spaces. While the installation of an alarm signal keyer does not relieve the radio operator of the responsibility of transmitting the alarm signal (subject to the direction of the master), either automatically or by hand, it will be apparent that greater accuracy of "timing" can be obtained with a properly designed automatic device.

The basic requirements of the Federal Communications Commission for an automatic alarm signal keying device are as follows:

(a) The device shall be designed so as to properly operate, on board ships at sea, the normal keying circuits of any transmitter approved by the Commission for use as a main or as an emergency transmitter in compliance with Section 354 of the Communications Act of 1934, as amended.

(b) Timing-adjustment controls shall not be accessible from the exterior of the device and shall be designed and housed so as to prevent adjustment by unauthorized persons.

(c) The keying mechanism shall operate so as to repeatedly transmit the International Automatic Alarm Signal. For this purpose the dashes transmitted shall have a duration within the limits of 3.8 to 4.2 seconds, and spaces between each of the twelve dashes constituting a series shall have a duration within the limits of 0.8 to 1.2 seconds. Spaces between each series of twelve dashes shall have a duration within the limits of 0.8 seconds to one minute.

(d) A single control, protected so as to avoid accidental manipulation, shall be provided for placing the device itself into full operation within a maximum period of 30 seconds. Once set into operation, the device shall be capable of continuously and properly operating without further attention for a period of not less than one hour.

(e) The automatic-alarm-signal keying device shall be capable of being energized solely by a source of power independent of the propelling power of the ship and independent of any other system; provided, however, that the device may be energized by the radio station emergency power supply and any storage battery power supply regularly used for operating a required automatic alarm receiver.

(f) When the proper operation of the device is dependent upon the maintenance of any inherent conditions of operation within relatively narrow limits, the Commission, as a provision of its approval, may prescribe such limits and require that the device shall include means for indicating to the operator when deviations from these conditions occur.

(g) Instructions concerning the proper adjustment of the device and the correct indication of any instrument incorporated for the purpose of revealing improper operation, shall be inscribed in a durable manner on a plate mounted on the device in a position to be easily read by the operator.

(h) Means shall be provided to insure that when the "On-Off" control of the device is placed in the "Off" position, the keying circuit to the radio transmitter(s) is automatically opened.

The AR–8651 keyer is designed for "panel" or "cabinet" mounting. A front panel with a clear plastic window permits observation of the motor driven timing cam and keying relay. Internal rubber shock mounts protect the vibrator, synchronous motor and other components from shipboard vibration. A 0–15 volt d-c voltmeter is used to read the 12-volt battery input to the keyer. A toggle type OFF-ON switch, recessed to prevent accidental closure, is mounted on the front panel. Fuses in the 12-volt battery input are panel mounted and may be conveniently replaced by unscrewing the insulated caps. Complete operating instructions are provided on the panel.

The principles of operation of the AR–8651 alarm signal keyer may be explained by referring to the schematic circuit diagram (Figure 13–25). The power source of the unit is 12 volts d.c., which is obtained from the radio station 12-volt emergency storage battery. The maximum current required from the 12-volt battery by the AR–8651 is approximately one ampere. If the AR–8651 is operated for a period as long as one hour, it will not consume more than one ampere-hour from the battery, and, therefore, does not appreciably affect the normal six-hour rating of the emergency battery.

When the OFF-ON SWITCH (S902) is placed in the ON position, this connects the 12-volt power source to the vibrator unit (K902) and the battery voltmeter (M901). The vibrator unit is a special device with a vibrating reed and polarity changing contacts designed to operate at a frequency of 60 cycles per second. The reed is maintained in vibration by means of the vibrator coil and contact assembly. A 0.5-μf condenser (C902), connected in series with a 10-ohm resistor (R901), is shunted around vibrator coil contacts to minimize sparking. The vibrator unit has a six-prong base which fits into a six-prong standard socket. A removable bracket is provided above the top of the vibrator unit to hold it in its socket.

The polarity changing contacts on the vibrator unit, in conjunction with the 20-μf power-factor-correction condenser (C901), deliver a 60-cycle voltage (approximately 22 volts) to the coil of the synchronous motor (B901). The armature in this motor rotates at a synchronous speed of 3600 rpm. The motor is provided with built-in gearing so that the speed of the motor shaft pinion is 60 rpm. This pinion then drives a large gear to which is attached the timing cam. This gear and cam assembly rotate at a speed of 12 rpm (one revolution in five second). The periphery of the cam is designed so that during four-fifths of a revolution (four seconds) the micro switch (S901) is closed, while for the remaining one-fifth of a revolution (one second) the micro switch contacts are open.

The contacts of the micro switch (S901) are equivalent to single-pole single-throw, and are used to control the coil of the keying relay (K901). Energy for the keying relay coil is obtained from the basic 12-volt d-c input to the device.

The keying relay (K901) has two electrically independent pairs of contacts (DPST), one pair of contacts is connected to terminals 3 and 4 while the other pair are connected to terminals 5 and 6. Therefore, on vessels which use separate emergency and main transmitters, the AR–8651 may be permanently connected to "key" either transmitter without additional switching. In the case of vessels with a combination main-emergency transmitter (single transmitter), terminals 5 and 6 would normally not be used.

The sequence of operations of the AR–8651 may be summarized as follows: Closing the OFF-ON SWITCH starts the vibrator which produces 60 cycle output, which in turn energizes the synchronous motor and starts the cam in motion. The cam opens and closes the contacts of the micro switch which in turn energizes the keying relay, and the contacts on the keying relay then keys the radio transmitter or transmitters as required.

The battery voltmeter on the AR–8651 is provided with a pair of red marks, the lower one at 10 volts and the upper one at 14.5 volts. The keyer will operate satisfactorily so long as the supply voltages are within these limits.

2. *Operating Instructions.* Transmit alarm signal, when authorized by master, as follows:

(a) Place 12-volt emergency battery on DISCHARGE, using switching facilities normally provided on emergency transmitter or emergency battery panel.

(b) Start up main transmitter on 500 kc, if ship's power is alive. Otherwise start up emergency transmitter on 500 kc on battery power. Be sure antenna is connected, press regular key and adjust transmitter for maximum 500-kc antenna current. Use A2 (modulated) emission. Do not lock telegraph key.

(c) Now place ALARM SIGNAL KEYER SWITCH in the ON position and let keyer run for about 90 seconds. Then turn keyer OFF and listen on receiver for answering vessel. Repeat keyer operation as often as necessary.

(d) When keyer is ON, check that relay inside operates and that voltmeter reads between red marks. Also note that antenna meter on transmitter is being "keyed."

(e) Keyer must be OFF when using telegraph key for SOS or for "manual" keying of alarm signal or for traffic.

(f) Familiarize yourself with this routine before an emergency. Test keyer each day with transmitter shut down (to avoid actual transmission of alarm signal).

(g) Failure of any component part in the AR-8651 will be disclosed by nonoperation of the keying relay. In such cases, manual timing of the alarm signal with the radio room clock should be employed and the normal telegraph key should be used.

3. *Maintenance.* The over-all operation of the AR–8651 keyer should be given a routine check once each 24 hours with the radio transmitters *not*

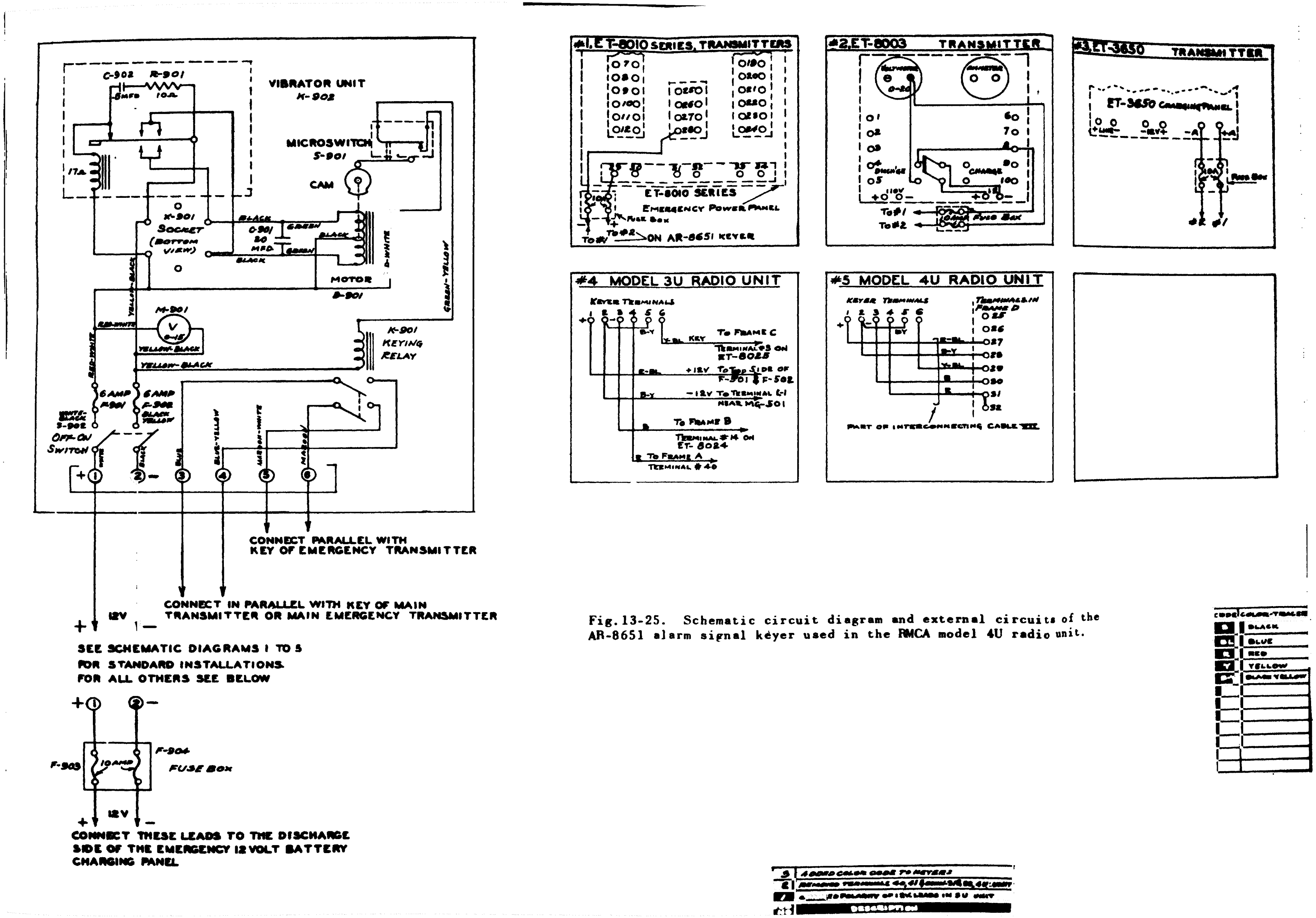
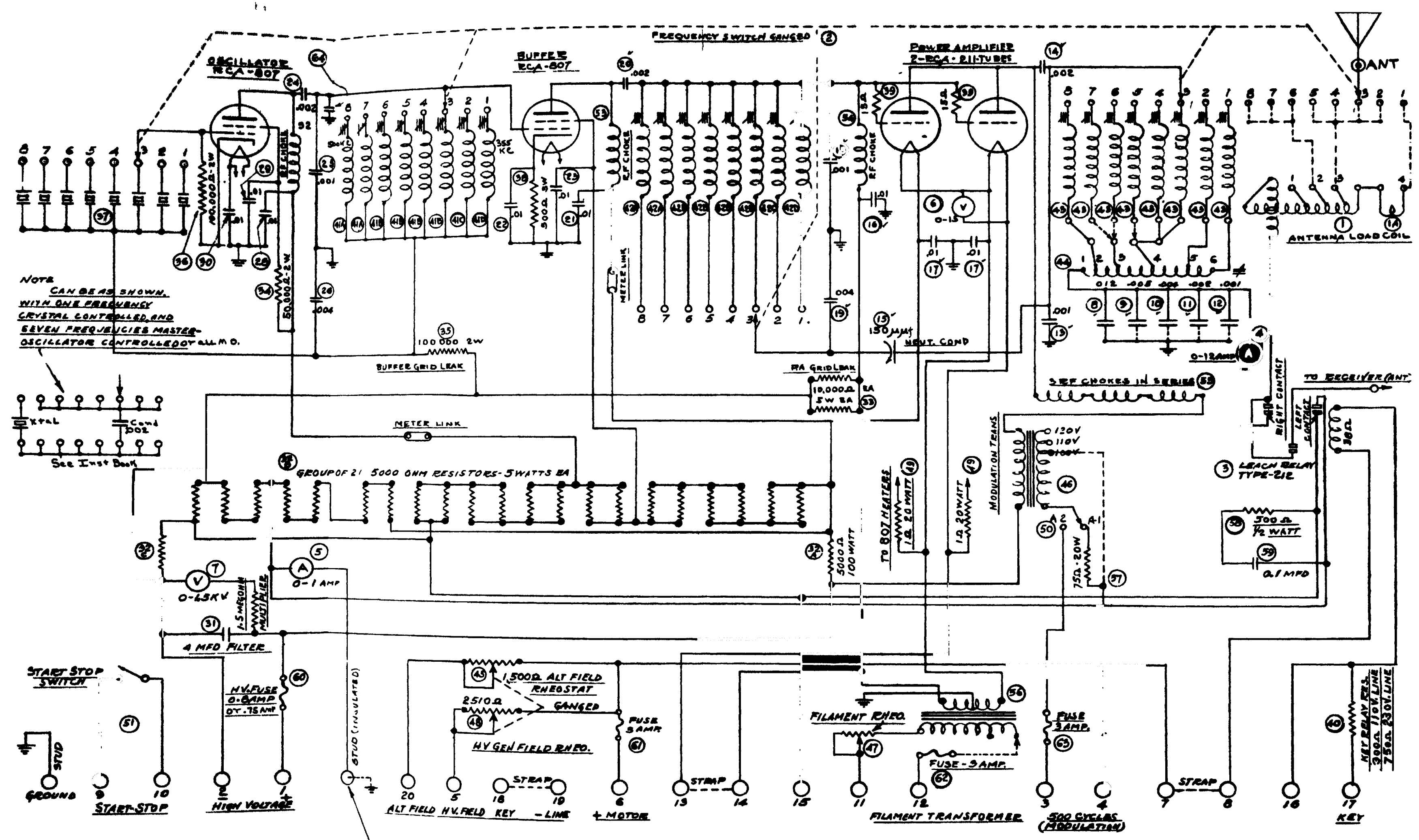


Fig. 13-25. Schematic circuit diagram and external circuits of the AR-8651 alarm signal keyer used in the RMCA model 4U radio unit.



NOTE CAN BE AS SHOWN, WITH ONE FREQUENCY CRYSTAL CONTROLLED, AND SEVEN FREQUENCIES MASTER-OSCILLATOR CONTROLLED OR ALL M.O.

THIS STUD IS CONNECTED TO THE D.C. AMMETER AND BECOMES GROUNDED BY THE TRANSFER SWITCH WHEN ET-8010-C IS USED WITH ET-8019, WHEN THE ET-8010-C IS USED WITHOUT THE ET-8019, THE STUD IS TO BE GROUNDED TO FRAME AS SHOWN.

	PART#45	PART#47	PART#48	PART#40	PART#3 SEC	PART#56	TAP
110VOLTS-DC	378-OHMS	25-OHMS	585-OHMS	300-OHMS	200-OHMS	S-7731	70V
230VOLTS-D.C.	1500-OHMS	75-OHMS	2510-OHMS	750-OHMS	200-OHMS	S-7731	160V
220VOLTS-3φ	378-OHMS	500-OHMS	585-OHMS	300-OHMS	200-OHMS	S-12406	220V
440VOLTS-3φ	378-OHMS	500-OHMS	585-OHMS	300-OHMS	200-OHMS	S-12406	440V
110VOLTS-1φ	NOT USED	25-OHMS	NOT USED	NOT USED	200-OHMS	S-7982	100V

Fig. 13-26. Schematic circuit diagram of the RMCA ET-8010-C-CA 200-watt marine radio-telegraph transmitter.

8 Frequency Transmitter USMC

in operation. It will be apparent that complete overall operation of the keyer and the transmitter cannot be undertaken, as this would cause transmission of the alarm signal.

The daily routine test should consist of turning on the keyer only and allow it to operate for approximately one minute. Note that the cam and micro switch roller operate freely, and that the keying relay opens and closes in synchronism with the movement of the cam. If no operation is obtained, check each of the 6-amp glass fuses inside the unit and also the external[2] 10-amp cartridge fuses in the fuse box. Normal operation of the vibrator unit results in an audible hum.

The contacts on the keying relay are made of silver and will ordinarily require no maintenance. If tests disclose poor contact, care should be taken not to clean the silver contacts with sandpaper or steel files. Contacts should be cleaned with alcohol or carbon tetrachloride and, when necessary, burnished with a relay contact burnisher or small strip of clean steel.

No lubricant should be applied to the driving pinion, the large cam gear, the cam or the roller on the micro switch. The synchronous motor itself is provided with sufficient lubricant sealed inside the case for the internal gearing of the motor.

The overall timing accuracy of the AR–8651 may be checked approximately once each three months, or whenever faulty operation is suspected, by carrying out the following procedure.

Each time the keying relay *closes* an audible "thump" can be heard. When the relay opens a "click" of lower audibility may be heard, but this "click" is to be ignored. Now it will be apparent that during every five second complete cycle (one cam revolution), there will be heard one relay "thump." Therefore, if the keyer is allowed to operate for an exact period of 120 seconds (24 alarm cycles), there will be heard 24 "thumps."

Start the keyer and observe the second hand of the radio room clock. Wait until the second hand approaches zero on the clock and listen carefully for the relay "thump," and at that instant note the position of the second hand. Then count the next relay "thump" as *one*. Continue to count each "thump" of the relay until 24 "thumps" have been heard. At the instant of hearing the 24th "thump," note the time from second hand of the clock. This time should indicate 120 seconds, plus or minus two seconds from the initial starting time.

As an example of the procedure outlined in paragraph above assume the first relay "thump" (the one not counted) is heard when the second hand of the clock is at four seconds. Counting is then begun and when the 24th counted "thump" is heard, the second hand will have made approximately two complete revolutions and will read 2, 3, 4, 5 or 6 seconds at the instant when the 24th "thump" is counted. On the other hand, if the 24th "thump" is observed to occur at a point on the clock lower than the two second mark, this indicates that the "timing" is too fast, while if it occurs at higher than the six second mark, this means that the "timing" is too slow. If a replacement vibrator does not give correct "timing" within the specified tolerance of plus or minus two seconds, the unit should be returned to a radiomarine service station for repair.

The over-all accuracy of the "timing" check outlined above may be explained in the following manner: In a 120 second test, an overall error of plus or minus two seconds is equivalent to an error in "timing" of only 1.67 percent. The primary purpose of this overall "timing" check is, of course, to verify that the vibrator and motor operation is normal. The "relative" accuracy of the dashes and spaces is determined by the cam itself, and the adjustment of the roller actuated by the cam. These adjustments are very carefully made and locked at the factory and should not be tampered with. However, in the event of major repairs or replacements, the procedure outlined in the following paragraph should be carefully observed.

Remove chassis dust cover which encloses the motor, relay, cam and micro switch assembly. Remove acorn lock-nut which will expose a hexagon head nut underneath. Now rotate the cam by hand until the roller attached to the micro switch arm is over the "low" surface of the cam. This is the surface which occupies four-fifths of the total cam periphery. If the roller arm adjustment is correct, it will be observed that the roller just *barely* touches or *almost* touches the cam. In no case should there be any appreciable pressure on the roller arm, nor should there be a clearance between the cam and the roller of more than .002 inch. If it is found necessary to readjust, loosen the locknut, which allows the micro switch to be rocked slightly, in order to set the roller with respect to the cam. Then carefully tighten the locknut, replace the protective acorn nut and observe the adjustment once more. The basic principle to be kept in mind is that the micro switch contacts must be *closed* when the roller is over the "four-fifths section" of the cam. Then, as the cam rotates so that the high section or one-fifth portion engages the roller, the micro switch contacts will open. It will be apparent that if the roller arm is set up so close to the four-fifths section of the cam, there will be excessive pressure on the roller arm which may keep the micro switch contacts permanently open. On the other hand, if the roller is adjusted too far away from the cam, this may result in failure of the contacts to open when the roller is on the one-fifth section of the cam. Accordingly, when the roller is set correctly as outlined above, normal operation and accurate "timing" of dashes and spaces will occur. Always replace dust cover after making any adjustments.

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[2] Not used in model 4U.

Important: When making any of the adjustments outlined in this section for "timing," it is important that the supply voltage be not less than 12 volts.

13–3. RMCA Model ET–8010–C 200-watt Radiotelegraph Transmitter—The ET–8010–C radiotelegraph transmitter is designed primarily for marine applications where a compact medium power transmitter is required. The design of this equipment embodies several features not heretofore available, such as quick selection of operating frequencies, plate modulation of the power amplifiers for A2 emission (modulated telegraphy), and the use of high efficiency iron core Litz inductances.

1. *Rating.* The transmitter is designed to deliver 200 watts or more to a standard 750-$\mu\mu$f, 4-ohm antenna, modulated at least 70 percent, for modulated telegraphy (A2) and 160 to 200 watts for continuous wave transmission (A1).

2. *Frequency Range.* The design permits the set to be pre-tuned to any eight frequencies in the band 350 to 500 kc (857 to 600 meters). The actual operating frequencies for which the transmitter is tuned appear on the frequency switch and in case it is desired to set up the transmitter for different frequencies within the specified range, removable nameplates are provided. Nameplates are available for the following frequencies: 355–375–400–410–425–454–468–500 kc. For ordinary service the transmitter is usually tuned to 355, 375 and 500 kc and five additional working frequencies within the band. The transmitter is designed for crystal control or master oscillator control of frequency. To change to crystal control, it is merely necessary to remove a small capacitor ana place the crystal holders on the mounting board provided.

3. *Vacuum Tubes.* Four tubes are used in the transmitter. The master or crystal oscillator uses one 807 tube. The buffer amplifier stage also uses one 807 tube. The power amplifier utilizes two UV–211 tubes in parallel.

4. *Power Supply.* The transmitter is designed for 115 volts d.c. or 230 volts d.c., and the appropriate motor generator set for the line supply voltage is included as part of the equipment. The motor generator set is a three-unit two-bearing machine, consisting of a d-c motor with slip rings for filament supply, a 1200-volt d-c generator for plate supply and a 500-cycle alternator for modulated telegraphy (A2). For 115-volt d-c supply the motor generator set is rated as follows: Motor—type LF/53, 110 volts, 11 amp d.c., 2500 rpm with slip rings to deliver 75 volts, 1.33 amp, at 83 cycles. High voltage generator, 1200 volts, .45 amp d.c., alternator 110 volts, 1.59 amp at 500 cycles. The 230-volt motor generator set is rated the same as the 110-volt unit, except for the motor which is rated 240 volts, 5 amp d.c. with slip rings to deliver 165 volts, .6 amp at 83 cycles. A-c drive motor generator may be supplied in special cases.

5. *Type of Circuit.* The transmitter utilizes a master or crystal-oscillator buffer-amplifier power-amplifier circuit with plate modulation on the power amplifier tubes through a modulation transformer for A2 or modulated telegraphy. The oscillator circuit contains eight small adjustable inductances for the eight spot frequencies. These coils are wound with Litz wire and have an adjustable iron core for varying inductance. A similar circuit arrangement is used for the buffer and power amplifiers. A special five-pole eight-position switch is used to select the appropriate circuits for the eight spot waves. The power amplifier is coupled to the antenna circuit by means of relatively high capacity condensers which are in series with the power amplifier tank circuit so that a minimum amount of harmonic power is transferred to the antenna system. The antenna circuit is tuned by means of a variometer and a tapped loading coil, the taps being automatically selected by the frequency switch. Break-in operation is provided by means of a special break-in relay. The schematic circuit is shown in Figure 13–26.

6. *Antenna Characteristics.* The transmitter is designed to cover the specified frequency range of any antenna whose characteristics fall between 500 and 1500 $\mu\mu$f with a resistance of 4 to 10 ohms.

7. *Transmitter Adjustments.* The transmitter is normally adjusted at the factory for the following frequencies: No. 1—355, No. 2—375, No. 3—400, No. 4—410, No. 5—425, No. 6—454, No. 7—468, No. 8—500 kc. The numbers one to eight correspond to the crystal mounting positions, the oscillator variable inductance adjustments, the buffer amplifier inductance adjustments and the power amplifier trimmer inductance adjustments. All of the above circuits are tuned from the right side of the vertical sub-panel which is made accessible by removing the right side panel of the transmitter. Two meter links are provided so that milliammeters may be inserted in the oscillator and buffer amplifier plate circuits. These links consist of two binding posts with a strap normally connected between them which is to be removed when metering and replaced after all adjustments are made. Each link is suitably marked. The meter used for the oscillator link need be no larger than 15 ma and should not be so large that it is difficult to read small changes in the order of one milliampere. The milliammeter used for the buffer amplifier plate current link should be approximately 0–100 ma range. The main plate current meter on the front panel reads all plate currents but since the oscillator and buffer plate currents are relatively low this meter conveniently indicates proper power amplifier plate circuit resonance. The transmitter is normally adjusted for the afore-mentioned frequencies using the oscillator as a master oscillator. If any changes are necessary from the frequencies to which the trans-

mitter is normally tuned, the following procedure should be used.

(a) Disconnect antenna from transmitter and remove both right and left side panels.

(b) Couple the pick-up coil of the frequency meter as loosely as necessary to the power amplifier tank inductance.

(c) Loosen all the locking nuts on the threaded rods extending through the vertical sub-panel for the frequency to be readjusted.

(d) Turn the plate voltage rheostat to the extreme counterclockwise position so that the generator voltage is about 700 volts.

(e) Adjust the filament voltage to 10 volts.

(f) Assume the 454 kc setting is to be adjusted. These are the No. 6 adjustments in the various stages. Connect milliammeters in the oscillator and buffer plate circuits. Disconnect the filament lead to the power amplifier tubes by temporarily removing the wire nearest the left-hand side of the set which goes to the filament terminals on the sockets. This enables the plate filament capacitance of the power amplifier tubes to remain in the circuit when adjusting the buffer, but prevents power amplifier plate current flow and unloads the buffer so that a sharp dip is obtained when adjusting the buffer. Adjust the plate voltage to approximately 700 volts. Now, if the set is master oscillator controlled, adjust the iron core in the oscillator coil until the correct frequency is obtained. If the set is crystal controlled, adjust the iron core in the oscillator until you get a single dip with an oscillator plate current of about 5 ma. If more than one dip is observed, with crystals, the plate current will be considerably higher than 5 ma, which is an indication that the iron core is greatly beyond its correct position. After the correct dip is determined in the oscillator, move the core screw counterclockwise about one-quarter to one-half turn, which will raise the oscillator plate current one or two milliamperes higher than minimum. Next adjust the iron core in the buffer stage for a true minimum, which will be between 5 and 10 ma with 700 plate volts. Now reconnect the power amplifier filament circuit permanently, disconnect the antenna, and tune the power amplifier iron core for minimum plate current, which will be about 60 to 80 ma on the panel plate ammeter with 700 plate volts. Connect antenna, raise plate voltage to its normal full-power value and tune antenna for maximum antenna current. If it is necessary to change the value of the antenna coupling condensers to load out the power amplifier properly, *keep in mind* that a change in antenna coupling capacitance de-tunes the power amplifier tank slightly and, therefore, the power amplifier iron core should be readjusted for a true minimum with antenna disconnected, each time the antenna coupling capacitance values are changed.

In the case of master oscillator sets, when checking the beat note, the note will, of course, change continuously whenever the oscillator iron core is moved. In checking for stability of crystal-controlled sets, with the correct oscillator adjustment the note will not change perceptibly when the core is properly adjusted. With crystals, if the core is moved clockwise the crystal will lose control and the circuit will act as a master oscillator, while if the core is moved counterclockwise the crystal will "lock in" and then if the core is moved slightly more counterclockwise the keying should be clean and crystal controlled.

(g) The antenna coupling condensers are five units mounted to the right of the break-in relay. From top to bottom, these condensers are: UC-3070 .001 μf, UC-3053 .002 μf, UC-3037 .004 μf, UC-3029 .005 μf, and UC-3276 .012 μf. The lower, or UC-3276, condenser must always be connected in circuit. Various combinations of the remaining four capacitors are used to match the antenna resistance. If the transmitter, when loaded into the antenna, shows more than approximately .45 amp plate current, additional coupling capacity should be connected in circuit. Keep in mind that, whenever the coupling capacitors are connected in a different manner than that received from the factory, it is necessary to reresonate the power amplifier tank circuit as outlined under paragraph (f).

(h) The antenna variometer has four stator taps. Counting from the rotor we refer to the taps as No. 1, No. 2, No. 3 and No. 4. When the transmitter leaves the factory these stator taps are terminated to the selector switch points necessary for an average antenna of 750 $\mu\mu$f and 4 ohms. Should the antenna characteristics be very different from the above values it will be necessary to change the connections from the antenna variometer to the selector switch. The proper connections are indicated in the following table.

500-$\mu\mu$F ANTENNA CAPACITANCE

	500 kc	468 kc	454 kc	425 kc	410 kc	400 kc	375 kc	355 kc
Antenna variometer tap number	2 or 3	2 or 3	3	3	3 or 4	3 or 4	3 or 4	4

750-$\mu\mu$F ANTENNA CAPACITANCE

Antenna variometer tap number	2	2	2 or 3	3	3	3	3	4

1000-$\mu\mu$F ANTENNA CAPACITANCE

Antenna variometer tap number	2	2	2	2 or 3	2 or 3	3	3	4

Always use lowest tap number that allows enough range on the "antenna tuning" dial for changes in antenna characteristics. A spare piece of copper tubing for connecting the variometer stator tap to the switch is provided and will be found tied to the wood supports of the antenna variometer on the upper left side of the transmitter.

(i) The inductance section of the power amplifier plate circuit is composed of a main coil with taps and provided with an iron core which is adjusted at the factory, together with eight trimmer inductances, any one of which may be inserted in series with the main coil, depending upon the position of the frequency switch. The main power amplifier tank coil is mounted vertically at the rear of the P.A. tubes. The adjustment of the iron core for this coil is made at the factory and there should be no occasion to change it. With the left side panel removed, it will be observed that the main power amplifier tank coil is provided with six taps. The lower end of this coil connects to the antenna coupling condensers, while the taps connect to the various trimmer inductances. The No. 1 trimmer, for 355 kc, connects to the top terminal of the main tank coil. The No. 8 trimmer connects to the second tap from the bottom end of the main tank. The five working wave P.A. trimmers connect to the main coil (item 44) as shown in Figure 13–26.

The range of the power amplifier trimmer inductances, when connected to the main taps of the main power amplifier tank coil, is as follows. No. 1 trimmer inductance connects to tap No. 6 (total coil), 350–375 kc. No. 2 trimmer inductance connects to tap No. 5, 375–400 kc. No. 3, No. 4, and No. 5 trimmer inductances connect to tap No. 4, 400–450 kc. No. 6 and No. 7 trimmer inductances connect to tap No. 3, 450–470 kc. No. 8 trimmer inductance connects to tap No. 2, 470–510 kc.

The number of turns on the main tank coil corresponding to the taps as mentioned above are, counting from the top of the coil:

Tap No. 6, entire coil, 41 turns.
Tap No. 5, 28 turns.
Tap No. 4, 19 turns.
Tap No. 3, 12 turns.
Tap No. 2, 6 turns.

The power amplifier neutralizing condenser is set and locked at the factory, and uses approximately four-fifths of its maximum capacitance.

(j) If the ship's radio receiver is used to check the note, and overload of receiver due to a strong signal makes this difficult, it is suggested that the receiver be tuned to one-half the frequency of the transmitter. For example, if 500 kc is being checked, tune the receiver to 250 kc. This will enable the second harmonic of the receiver to beat the transmitter fundamental frequency and will avoid receiver overload.

8. *General Instructions.*

(a) Do not exceed 1200 volts or .45 amp plate input.

(b) Always keep the filament voltage adjusted to 10 volts.

(c) Keep all shields of transmitter fastened tightly to frame.

(d) Keep break-in relay contacts adjusted with minimum clearance for best keying. When this relay is properly adjusted, no sparking should occur on the right pair of antenna contacts and only slight sparking should be observed on the left pair or power contacts. Make sure that the lower contacts, which connect the antenna circuit to the receiver, are always open when the relay coil is energized.

(e) Keep the transmitter and motor generator free from dust and oil. Occasional dusting of the transmitter and all nameplates on the panel will help maintain new appearance. The isolantite switches in the tank circuits and antenna circuits should be cleaned about every six months from accumulations of dirt and dust which might cause flashover. Do not use any form of polish on chromium trim or nameplates.

9. *Note on Installing Crystal.* Crystal holders should be installed on the mounting board so that the RCA monogram on the holder is *nearest* the front panel or the left side panel.

If a total of eight crystals are used it is necessary to remove the .002 condenser from the crystal mounting board and also unsolder the paralleling strap connection on the board that is *nearest* the frequency switch (not the strap connection near the front panel.

If less than eight crystals are used, it is necessary to parallel the connection studs and connect the .002 condenser *for those frequencies* which are to be master oscillator controlled. For example, one crystal controlled and four master oscillator frequencies could be used.

13–4. RMCA Model ET–8010–CA 50-watt Emergency Radiotelegraph Transmitter—The ET–8010–C transmitter described in Section 13–3 is designed so that by the addition of an emergency power panel and a small dynamotor, the ET–8010–C may be used for both a main and an emergency transmitter when permitted by law. The transmitter is designated as ET–8010–CA when equipped with emergency power apparatus. The same circuits are utilized throughout, the only difference being that for emergency operation, one power amplifier tube is disconnected and the plate supply is obtained from a small emergency dynamotor which is driven from the 12-volt storage battery. A suitable 12-volt storage battery, to provide six hours' emergency operation, should have a capacity at the 6-hour rate of 256 ampere-hours. A 17-plate battery is usually employed for this purpose.

1. *Rating.* The rating of the equipment when used as a main transmitter is as specified in Section 13–3 of this chapter. When used as an emergency transmitter, the input to the final stage is greater

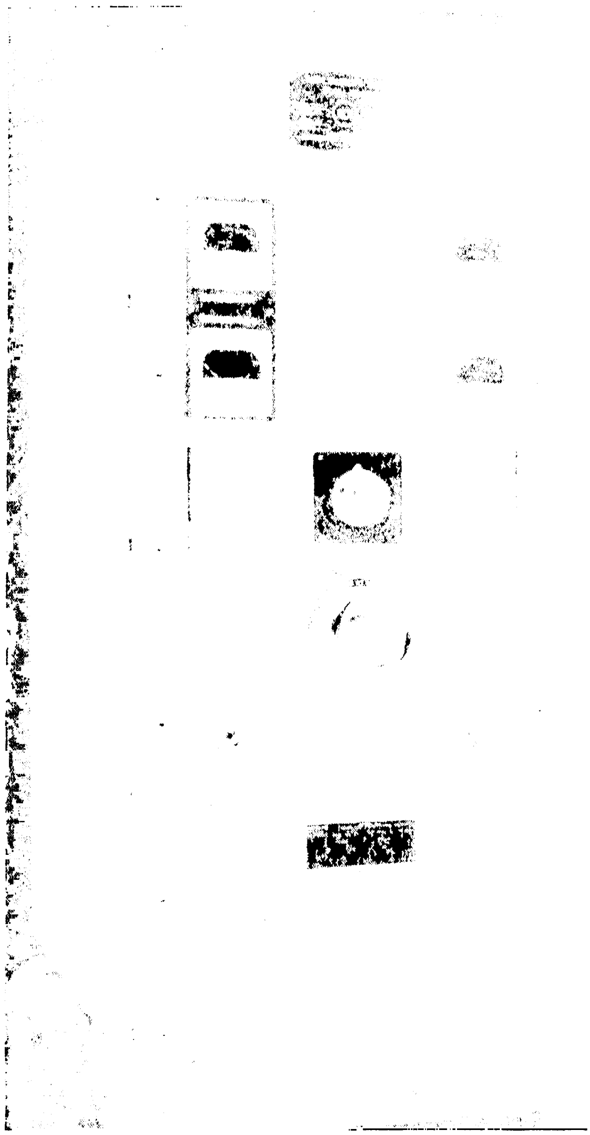


FIG. 13–27. The RMCA ET-8010-CA main and emergency radiotelegraph transmitter.

than 100 watts and the output is 50 or more watts into the antenna circuit when used with a standard 4-ohm 750-$\mu\mu$f antenna.

2. *Frequency Range.* Any one of eight spot frequencies for which the main transmitter is adjusted may also be used when the transmitter is operated from the emergency power supply.

3. *Vacuum Tubes.* The same vacuum tubes are used with the exception that in order to conserve battery drain, only one power amplifier tube (UV-211) is used when the transmitter is functioning from the emergency supply.

4. *Power Supply.* The rating of the emergency dynamotor type MT4/KS1 is as follows:

Motor—⅛ H.P., 11.5 volts, 28 amp d.c., 2500 rpm, compound wound.
Generator—575 volts, .25 amp d.c., compound wound.
Alternator—55 volts, .91 amp, single-phase, 500 cycles.

When the transmitter is used with emergency power supply, the 12-volt line current required is approximately 37 amp.

5. *Operation.* In case of failure of the ship's main power supply, the radio operator should observe the following procedure to operate the transmitter under emergency conditions:

(a) Throw CHARGE-DISCHARGE SWITCH to DISCHARGE position.

(b) Throw POWER TRANSFER SWITCH to EMERGENCY POWER SUPPLY position.

(c) Start dynamotor with START-STOP SWITCH. The radio transmitter may now be used as in normal service except that the plate voltage will be approximately 575 to 600 volts and the plate current approximately .23 amp. While either A1 or A2 emission may be used, under distress conditions, A2 would normally be employed. Since a lower value of antenna current is obtained under emergency operation from the 12-volt battery, the operator should take special care to resonate the antenna circuit carefully for maximum antenna current. While the battery furnished with the equipment will provide six hours' operation as required by law, appreciably longer service may be obtained if the operator shuts down the dynamotor during extended listening periods. However, since approximately 15 seconds are required for the tubes to heat up, the dynamotor should not be shut down when it is necessary to reply quickly under distress conditions.

13–5. Mackay Radio Transmitter 150AY (Installed on Liberty Ships with 167AY High-frequency Transmitter)—Radio transmitter 150AY is designed especially for use as a main and emergency transmitter for use on cargo vessels. It provides for quick change to any one of five frequencies in the intermediate-frequency range of 350 to 500 kc (845 to 600 meters). Automatic break-in operation is obtained by means of a relay which transfers the antenna from "Send" to "Receive" when the transmitting key is opened. The transmitter is rated to deliver in excess of 200 watts A-1 (CW) and over 300 watts A2 (ICW) into an antenna system of 750-$\mu\mu$f equivalent capacitance, and 4 ohms resistance, on all operating frequencies when operating from the ship's supply of 115 volts d.c. Emergency operation of the equipment from the 24-volt battery provides an output in excess of 50 watts A2 (ICW) on all frequencies. A1 (CW) output of approximately 40 watts is also available. Emergency operation for a period of six consecutive hours, as required by the Federal Communications rules and regulations, is provided. The transmitter is designed to operate into antennas of from 1 to 14 ohms resistance, and from 600 to 1500 $\mu\mu$f equivalent capacitance. Essentially sinusoidal modulation of approximately 720 cycles is obtained for ICW. The degree of modulation is substantially complete in all cases greater than 85 percent.

Switching facilities are provided for charging and discharging the emergency batteries, for connecting the transmitter to either the main or emergency generator, and for starting either motor generator set. Meters are placed in the battery and transmitter circuits for determining all important and essential conditions of operation.

1. *Frequency Stability.* The maximum frequency deviation from a pre-set value will in no case exceed plus or minus .1 percent due to all causes, i.e., antenna tuning, temperature variation, line voltage variation, vibration, plate and filament voltage fluctuation, modulation, keying, etc. The precision to which a frequency can be set depends only upon the precision of the frequency standard used for comparison.

2. *Power Supply and Power Equipment.* Included within the transmitter are the necessary transformers, rectifier and filter components for converting the 720-cycle a-c output of the motor generators to the correct voltages and currents for operating the vacuum tubes. The transmitter power supply consists of a single-phase full-wave mercury vapor rectifier with a single-section filter, filament transformer, power factor condenser, and a modulation transformer to plate modulate the final stage. A simple wave filter is provided to insure that the wave form of the modulating voltage is essentially sinusoidal.

3. *Motor Generators and Starters.* The main motor generator (motor generator 116A) is mounted on rubber vibration absorbing cushions, and installed in the lower compartment of the section housing the transmitter. This machine is a single unit two ball bearing, drip-proof motor alternator. Approximately 75 volts at 120 cycles is taken from slip rings on the motor to furnish filament power. The plate power, which is provided from the alternator end of the machine, is 200 volts at 720 cycles. The machine is designed to operate the transmitter satisfactorily with line voltages ranging from 90 to 120 volts. A field rheostat located on the front panel of the transmitter controls the 720-cycle output voltage of this machine. Filters are included in the terminal box and at the generator and motor brushes to reduce electrical noise interference to nearby receivers over the operating range of frequencies. The starter for this motor generator is mounted in the base of the transmitter section, to the left of the motor generator. This starter consists of an escapement type device with suitable starting resistance to bring the motor up to speed without placing an excessive load on the d-c line. In addition, this starter is equipped with a pair of auxiliary contacts which function as a time delay of 15 seconds to prevent premature application of plate voltage to the mercury vapor rectifier tubes when starting the equipment.

The motor generator used with the battery power supply is of identical size and construction as the main machine described above. This motor generator (type 120A) produces 120-cycle power equivalent to that of the main machine, and 720-cycle power at approximately 100 volts, as determined by a field resistor in the terminal box of the motor generator. The motor and generator field are wound to operate on 24 volts. A starting circuit, consisting of two relays and a series resistance, causes the motor generator to come up to speed smoothly, and without excessive current inrush. A time delay circuit, consisting of a relay and thermal delay strip, prevents the application of the emergency power until the rectifier tubes have heated. This unit is mounted on the right rear of the transmitter base.

Both generators are mounted on separate metal pieces, to which are attached the generator cushions. If it is desired to remove a generator for service or inspection, it is necessary only to detach the bolts which secure the two independent pieces to which the cushions are attached, and slide the machine forward.

4. *Method of Signaling.* Keying of the transmitter is accomplished by means of a break-in relay which is operated from the 115- or 24-volt supplies, depending upon whether main or emergency operation is employed. The power contacts of this relay break the power input to the plate transformer of the mercury vapor rectifier. For ICW operation, the 720-cycle voltage is filtered to produce a good wave form and is applied to the primary of the modulation transformer which plate modulates the final stage in a conventional manner. Change from CW to ICW operation is accomplished by the "CW–ICW" switch at the right center of the transmitter panel. This switch closes the circuit from the generator to the primary of the modulation transformer in the "ICW" position. The transmitter functions in identical manner regardless of whether the main or emergency motor generator is in use. The panel switch marked POWER connects the 120- and 720-cycle power of whichever machine is in use to the transmitter components. The battery driven generator is arranged to provide but one half the 720 cycle output voltage of the main machine, resulting in reduced transmitter output, but the operation of the transmitter otherwise is identical in either case.

5. *Type of Circuit.* The radio circuits of the transmitter shown in Figure 13–28 include a low power master oscillator, an untuned intermediate or buffer amplifier and a final amplifier. The master oscillator circuit employs a 210 or 801 tube in a self-excited oscillator circuit of the tuned plate, grid

feedback variety. A threaded ceramic coil form and low temperature coefficient aged condenser are used to improve the frequency stability and reduce frequency variation over long periods and under varying conditions of operation. Independent trimmer condensers are supplied for adjustment of the five frequencies. These trimmer condensers and the associated taps on the oscillator coil are selected by the frequency switch located at the left center of the transmitter panel. The leads from the "frequency" switch may be pre-set at installation, to taps on the oscillator coil which provide operation on any five frequencies in the range 500 to 350 kc. The five adjustable trimmer condensers are located on a vertical panel accessible from the left side of the transmitter by opening the left side door. These trimmers are equipped with locks to prevent changing of their capacity due to vibration after adjustment. The intermediate or buffer amplifier employs a single F-123-A tube with cathode bias protection against loss of excitation. Its output is impedance coupled by means of suitable radio frequency chokes and blocking condenser to the grids of the final amplifier tubes. The final amplifier employs two F-123-A tubes in parallel. These tubes, which are cushion mounted, are also protected from loss of excitation by means of cathode bias. The plate circuit of the final amplifier contains a radio frequency transformer for transferring the energy from the tubes to the antenna circuit. The primary of this transformer is a high impedance, roughly resonant in the middle of the band of frequencies over which the transmitter is required to operate. The secondary of this radio frequency transformer is wound on a ceramic form and consists of a few turns with frequent taps. This provides for adjusting to various antenna resistances. This transformer is located at the right side below the middle shelf, and may be reached by tilting the transmitter panel outward to its halfway point. Its secondary is connected in series with the antenna loading coil. This antenna loading coil is located on the upper right front corner of the transmitter shelf, and consists of a tapped coil with a rotor which is controlled by the knob marked ANTENNA TUNING at the upper right of the transmitter panel. A switch at the rear of the coil, actuated by the rotor, is a part of the coil assembly. This switch changes the inductance by means of changing the taps on the stator winding as the rotor passes through the 180° position. An auxiliary contact on this switch opens the power supply so that the switch is not permitted to change the taps while radio frequency energy is in the antenna circuit. By this means any antenna, whose equivalent capacity falls in the range of 600 to 1500 $\mu\mu$f, may be tuned without an additional wave change control. The antenna circuit also includes one pair of contacts of the keying relay. These contacts serve to transfer the antenna from TRANSMIT to RECEIVE position. In order to protect against excessively high plate voltages and abnormal conditions of operation, a glass enclosed, gas filled protective gap is placed at the high potential end of the radio frequency transformer primary and a high resistance in series with this gap limits the current upon discharge, the direct current component of which is caused to operate a relay, whose coil is in series with this limiting resistor. The contacts of the relay are in the keying circuit and open the power to the primary of the plate transformer upon discharge of the gap. The purpose of this protective system is to prevent damage from abnormally high voltages which may possibly appear on the primary of the radio frequency transformer. An auxiliary spark gap is located immediately below the glass enclosed protective gap. If the glass enclosed gap should fail the auxiliary gap will protect the transmitter.

6. *Metering Facilities.* Five meters are mounted on the front panel. The left-hand instrument is a d-c ammeter for indicating the rate of current passing through the emergency battery during charge. This meter will normally read .5 amp or 8 amp, depending upon whether the battery is being charged at a trickle or full charge rate. The second meter from the left is a d-c milliammeter which is switched by means of the knob below it to indicate oscillator plate current, intermediate or buffer amplifier plate current, and final amplifier plate current. The center instrument is the antenna current meter, indicating the current in the base of the antenna circuit during transmission. This meter is used in tuning the transmitter, resonance being determined by a maximum reading of this instrument. The fourth meter from the left is the filament voltmeter, which reads the filament voltage of the transmitting tubes. This meter, when adjusted by means of the filament rheostat to read 10.5 volts, indicates correct adjustment of all tubes. The right-hand meter is connected across the 24-volt battery during discharge, and indicates the battery voltage at the transmitter.

7. *Switching Controls.* The power controls are placed above and between the filament and field rheostats. To the left of the row of three switch knobs is one labeled POWER. The purpose of this control is to connect the transmitter to either the main or emergency generator. This switch controls the 120 and 720 cycle power leads. In addition it arranges the keying relay to operate on 24 or 115 volts, as the case may be. The center switch, which is marked BATTERY, when thrown to the left, places the battery on charge, or, if thrown to the side marked START, connects the battery to the starting relay in the terminal box of the 120 motor generator, starting the machine. During charge, the current rate is controlled by a toggle switch below this BATTERY switch. This toggle switch, when in the upper, or FULL CHARGE position, causes the battery to be charged at an 8-amp rate. When thrown to the lower, or TRICKLE CHARGE side,, a .5-amp rate

results. This switch also selects the speed at which the ventilating fan operates. During trickle charge, when the heat generated by the charger resistor is low, the fan operates at a low speed. When the battery is placed on full charge, the fan is speeded up, so as to completely dissipate the heat from the charger resistors. This switch can also be used to control the speed of the fan when the transmitter is in use, though under ordinary conditions, the low rate of speed is quite adequate to discharge the heat generated by the transmitter tubes and power components. The right hand switch is placed in the 115-volt d-c line, and when thrown to ON position, operates to start the main motor generator, and connect the d-c line to the keying and field circuits.

On the lower left of the panel is placed a filament control, for adjusting the filament voltage of all tubes. At the corresponding position on the lower right of the panel is the field rheostat, which controls the power output of the main generator.

To the left center of the panel is the FREQUENCY switch, which causes the oscillator to function at any of five predetermined frequencies in the range 350–500 kc. A lamp in the center of the panel indicates when the transmitter is running. To the right of this lamp is a knob which selects either A1 (CW) or A2 (ICW) emission. This control switches the 720-cycle output of the generator in use to the primary of a transformer, which modulates the d-c input to the plates of the final amplifier tubes. At the top right is the antenna resonating control, which operates the antenna variometer and associated switch described previously.

8. *Transmitter Construction.* The transmitter is a single unit, consisting of a base, on which the power components are placed, a shelf containing the r-f components, and a front panel, to which the base, shelf and all additional equipment and controls are attached. The front panel is hinged at the bottom, and so balanced as to permit it to swing outward with little effort. When half open, a spring stop engages with the main frame angle, holding the transmitter panel half open. If it is desired to open the panel further, the spring catch can be pressed in with the finger, permitting the panel to open 90°, where it is held with another stop. The transmitter is cabled to two terminal blocks mounted on the base, extra flexible hinge wire with flame proof insulation being used. The cable folds under the transmitter base, where it is well protected. The antenna lead from the break in relay, hinges at the right hand side, and is not included in the main hinge cable. Grounding connections are also provided on both sides of the hinge. The power supply components mounted on the base permit removal of any part without requiring removal of any other part. All power supply components may be removed from the base by means of screws, which are tapped into the base, without requiring accessibility to the bottom of the base or the handling of nuts, cap screws and the like. The radio frequency components are mounted on an intermediate shelf, which provides excellent accessibility. The antenna terminal is brought to a spring clip on the top edge of the transmitter panel, which engages with an insulated connecting plug when the transmitter panel is in place. Two handles are supplied to facilitate handling, and to hold the panel securely in place. The transmitter panel is heavily copper plated before painting to improve its r-f characteristics and to prevent rust should the paint become chipped. The r-f shelf is constructed of solid copper cadmium plated so as not to effect the r-f inductances adversely. The base is of cadmium plated steel. The F-123-A tube sockets are cushion mounted.

The wiring diagram for radio transmitter 150AY, Figure 13–28, illustrates the wiring of the transmitter components. The upper section represents the transmitter proper, while the lower section contains the switching facilities and terminal provisions for battery charging, and selecting of either emergency or main generator supply. The wiring to the switches is exactly as shown on this diagram, the connections being shown as viewed from the rear. The emergency time delay relay and thermostat are shown on the lower right of this diagram. These parts will be found mounted on the right rear of the transmitter base. Time delay for the main generator is provided by a special delay contact in the starting mechanism.

9. *Adjustment of Transmitter.* The plate, modulating and filament transformers are equipped with taps corresponding to the maximum generator voltage which would be obtained at various d-c line voltages. The average d-c supply voltage may be ascertained from an observation of the line voltmeter on the right hand section of the Marine Radio Unit, and the transformers adjusted in accordance with the following table:

Line Voltage	Plate Trans. Tap.	Modulation Trans. Tap.	Filament Trans. Tap.
110 to 120	0–255	0-255	0–73
100 to 110	0–235	0–208	0–60
90 to 100	0–210	0–190	0–60

Although the transmitter can be made to deliver full power at the voltage of the line over the above ranges of 90 to 120 volts, it is adjusted at the factory for 115-volt operation. Unless it is noted that the average voltage is less than 110 no adjustments should be altered. If line voltage fluctuations are prevalent, the transformer taps must be set for the highest line voltage which will be experienced.

After the antenna has been erected, and equipment has been installed in accordance with the foregoing installation instructions, proceed as follows:

Place in the sockets in the base section, two 866-A tubes. On the shelf insert an 801 or 210 tube in the oscillator socket and an F-123-A tube in each of the three large sockets. Note that voltage is indicated on the line voltmeter, and make sure that fuses are inserted in the transmitter, and in the fuse clips for the 24-volt battery, below the line switch in the right base section. Turn the POWER switch on the transmitter panel to MAIN. Place the BATTERY switch in OFF position. Turn the LINE switch to ON. The generator should start smoothly. Adjust the filament rheostat so that the filament voltmeter reads 10.5 volts. Allow the transmitter to run in this condition for 15 minutes before pressing the key. This permits the mercury in the rectifier tubes to evaporate from the envelope and elements. This 15-minute warm-up period should be observed whenever new mercury vapor tubes are inserted in the transmitter. It should be noted that the ventilating fan is set in motion by the starting of the transmitter. This fan will operate only when the main motor generator is in use.

Open the transmitter panel to the halfway point, which provides access to the antenna coupling transformer and the antenna tuning variometer. On the rear of the variometer is a switch, which transfers the antenna circuit inductance from one value to another as the variometer is tuned through its range. The two leads from the switch must be connected to terminals of the variometer which will provide tuning over the entire frequency range with the antenna to be used. The variometer is equipped with three taps. The first is located on the upper end of the coil, near the switch panel, the second at the lower end of the coil near the switch panel, and the third or maximum inductance tap is located at the lower end of the coil toward the front panel. In adjusting these taps the lead from the upper switch terminal must be placed on the terminal which provides resonance at 500 kc at some point on the variometer dial between 0 and 100. This will be tap 1 if the antenna is 800 $\mu\mu$f capacitance or greater, and tap 2 if the antenna capacitance is less than this value. If the upper switch lead runs to variometer tap 1, the lower switch lead should be placed on coil tap 2, and if the upper switch lead runs to coil tap 2, the lower should be connected to coil tap 3. When so arranged, resonance will be obtained on all five frequencies at some position on the variometer dial.

The two leads which run to the taps on the coupling transformer (the ceramic form on the underside of the shelf directly below the antenna variometer) vary the loading of the amplifier tubes. The number of turns to be used will depend upon the resistance of the antenna. With the FREQUENCY switch on tap 3, corresponding to a frequency of approximately 400 kc, the CW-ICW switch on CW position, and the field rheostat turned clockwise all the way to provide full power from the generator, adjust the coupler taps until an amplifier plate current of 350 ma is indicated when the antenna is resonated with the ANT. TUNING knob. The transmitter is adjusted in the factory for 500 kc on tap 1, 375 kc on tap 4 and 355 kc on tap 5, with taps 2 and 3 placed on intermediate assignments in the band. At 500 kc the amplifier plate current reading may be slightly higher than 350 ma and at 355 kc it may be slightly lower. In adjusting the coupler taps, use an equal number of taps on each side of the center of the coil if possible. If it is necessary to use one turn less than an equal number, this turn may be removed from either side of center. It will be noted that when the CW-ICW switch is thrown to the ICW position, the amplifier plate current drops slightly due to the reduction in plate voltage when the added load is imposed upon the generator. The antenna current should rise 10 percent or more over the CW value.

With the PLATE CUR. switch on OSC position, the oscillator plate and grid current is read and should be approximately 50 ma on all frequencies. With the switch on BUF position, the plate and grid current of the buffer stage is read. This should read about 80 ma, but may drop to 50 at the central frequencies, and rise to 120 at the low-frequency end of the band. The switch should be left on the third position, marked P.A., where it acts as a guide for the operator in making antenna adjustments.

With the CW-ICW switch on CW position, check the adjustment at all frequencies. Use a heterodyne type frequency monitor if possible. If such an instrument is not available, use a General Radio precision wavemeter, type 724, or equivalent. Open the left-hand cabinet door, revealing five condenser controls, numbered 1 to 5, corresponding to the numbering on the FREQUENCY switch. Each condenser is a vernier frequency adjusting device for its corresponding frequency. If a heterodyne type wavemeter is used, adjust it for 500 kc. Set the FREQUENCY switch on transmitter position 1, tune the antenna variometer to obtain maximum antenna current, and adjust the small condenser numbered 1 until the beat note in the monitoring meter indicates zero beat. Similar procedure should be followed for each frequency in turn. If the transmitter is not to be changed from its factory adjustments, the frequencies may be checked with the 128AX receiver, by throwing the ANTENNA switch on the receiver to EMERG position, and reducing the r-f gain to a minimum. The receiver is directly calibrated and the calibration is sufficiently accurate for rough frequency check.

If a precision wavemeter with a deflecting instrument, such as the General Radio wavemeter mentioned, is used, the antenna should be resonated before the frequency is checked. If the frequency is found to be a trifle high or low, the capacitance of the associated trimming condenser should be increased or decreased slightly, and the antenna resonated *before* checking the frequency. Do not attempt to tune the oscillator to the wavemeter, as maximum deflection of the wavemeter may result from resonance of the antenna circuit on other than the desired frequency. Should the range of the trimming condenser be insufficient to tune the oscillator to the desired frequency, it will be necessary to decrease or increase the inductance a turn. This is accomplished by unscrewing the three screws which secure the aluminum cover of the oscillator coil, at the left front of the center shelf, and removing this cover. With a soldering iron, disconnect the lead associated with the switch tap in use from the coil and place the lead on the next higher turn if the frequency is high, or on the next lower turn if the frequency is low. While it is not contemplated that any condition will normally arise which will make inductance change necessary, taps have been provided to permit tuning to any frequency in the entire range from 350 to 500 kc. Should it become desirable to place the transmitter on other than its adjusted frequencies, this can be accomplished in the manner outlined. The coil cover should be carefully put in place before checking frequencies. When adjustments are complete, the trimming condensers should be locked in position.

Should the r-f voltage across the amplifier plate coil become dangerously high, a discharge will occur across the gap in the cartridge which is mounted on the shelf at the rear of the antenna variometer. This discharge causes a relay to operate, opening the keying circuit. This relay is of the slow releasing type, and after a period of approximately one-half second the relay releases, again applying power to the transmitter. Should the condition which has caused the excessive voltage across the plate coil be unchanged, a discharge across the cartridge gap will again operate the relay and open the keying circuit. This cycle of operation will persist until the condition is corrected. Under normal operation the r-f voltage across the plate coil will be insufficient to result in a discharge of the gap, and the operation of the relay. Should the antenna be completely detuned under full power conditions, or the power input raised beyond the point of safe operation by incorrect transformer tapping or some other means, a discharge will occur at the gap, operating the protective relay and preventing damage to transmitter parts. The additional gap beneath the cartridge will function should the cartridge become broken or inoperative.

Having checked the above, throw the LINE switch to OFF. Turn the POWER switch to EMERG position. Turn the BATTERY switch in the center of the panel to START. The motor generator in the base of the right-hand section should start smoothly. The filament voltmeter may read slightly less than with main power. Adjust the filament rheostat for 10.5 volts. Turn the CW-ICW switch to ICW position. (It should always be in ICW position when emergency is used.) Test the transmitter output as before, noting that the oscillator plate current is about 20, the buffer plate current about 30 and the final plate current about 150 ma. No adjustments should be made to any circuits to obtain the above readings, as those made for main operation will result in readings as above. If other than the currents indicated are obtained, check the a-c output of motor generator 120A (between ground and terminal 21 of the interconnecting block), and adjust the variable field resistor (R17 on RC-1291-14) in the terminal box of motor generator 120A to obtain 100 volts across these points. This adjustment has been made in the factory, and should not be necessary in the field. During the above adjustments, the BAT. VOLTAGE meter at the top right of the transmitter panel should read 24 volts. Should the battery voltage be higher or lower, readings given above may vary.

Throw the BATTERY switch to CHARGE position. If the toggle switch below it is in TRICKLE CHARGE position, the CHARGING CURRENT meter at the top left of the panel should read .5 amp. and the ventilating fan should operate at slow speed. When the toggle switch is thrown up to FULL CHARGE, the meter will read 8 amp, and the fan will operate at increased speed. During operation of the transmitter, or at any time that the charger is not in use, this toggle switch should be kept in TRICKLE CHARGE position to prevent operation of the fan at high speed when the transmitter is operated. Under conditions of extremely high ambient temperatures, it may be desirable to run the fan at high speeds when the transmitter is operated, in which case the toggle switch may be left in FULL CHARGE position, but this condition represents the unusual.

10. *Operation of Transmitter 150AY.* Except when it is desired to use the battery power, the POWER switch on the panel should be kept in MAIN position. To place the transmitter in condition for main operation, throw the LINE switch to ON position. After the pilot light operates, and the motor generator in the base of the left-hand unit comes up to speed, adjust the filament rheostat until the filament voltmeter reads 10.5 volts. Set the FREQUENCY switch on the position corresponding to the desired frequency of operation (position 1 for calling purposes). After a period of approximately 15 seconds, depress the telegraph key, and resonate the antenna by adjusting the antenna variometer until maximum current is indicated on the ANTENNA CURRENT meter. If the position of the antenna variometer has been listed on the card attached to the front panel, the variometer may be adjusted to the prescribed dial reading at the same time the FREQUENCY switch is adjusted. For normal operation the field rheostat should be set at a point where 300 ma is indicated on the PLATE CURRENT meter when reading the current in the final amplifier circuit (PLATE CURRENT switch in P.A. position). The transmitter may be safely operated at full power,

or the power may be reduced to one-half normal output, if desired, by adjustment of the field rheostat. It is poor practice to use more power than is required to effect satisfactory communication.

CW or ICW may be obtained by throwing the switch so labeled to the proper position. The power output of the transmitter for any given field rheostat adjustment is greater when operating ICW than when CW is used. Should the protective relay operate during adjustment of the transmitter, it is an indication that adjustments are incorrectly made. If the power input is dangerously high, or the antenna circuit detuned, disconnected or grounded, the relay may operate whenever the key is pressed. Correcting the condition will cause the relay to cease operating. The cartridge associated with the protective relay, or the gap beneath it, should never be tampered with. In case of failure or destruction of the cartridge, the gap beneath it will provide protection, but the cartridge should be replaced at the first opportunity. Frequency changing is accomplished by setting the frequency switch to the position representing the desired frequency and adjusting the antenna tuning to obtain a maximum antenna current. If the plate current exceeds 350 ma, the plate voltage should be dropped by means of the field rheostat.

11. *Emergency Operation.* To place transmitter 150AY in operation from the emergency battery, turn the POWER switch to EMERG, and the BATTERY switch to START. The CW-ICW switch should be in ICW position. Be sure the LINE switch is OFF. Adjust the filament voltage to 10.5, and after waiting 15 seconds for the time delay to function, press the telegraph key, and resonate the antenna as before. The output will be less than with main power, but operation is in no wise different.

Note: It is possible to cause both generators to run simultaneouly, and no harm is done by so doing. There is no point in this procedure however, as but one machine can be used at a time. It should be carefully ascertained that the BATTERY VOLTAGE meter does not read when the emergency supply is not in use. This meter reads only when the BATTERY switch is in START position.

12. *Precautions to Be Observed.* Since the voltages within the transmitter during operation are dangerous to human life, great caution should be observed when the side doors are opened for making internal adjustments. The only adjustment which may be made with the transmitter energized is the setting of the five trimmer condensers, the controls of which are at ground potential and may be handled with safety. The motor generator should be shut down whenever anything else within the transmitter is to be touched.

The filament voltmeter should not be allowed to drop below 10 volts with the key down, and the transmitter adjusted for operation. The voltage may be adjusted to 10.5 volts with the key up, and operates normally with the filament voltmeter reading 10.3 volts, key down. If the filament voltage is allowed to drop below 10, rapid deterioration of the rectifier tubes results. Premature failure of the rectifier tubes usually occurs from low filament emission caused by undervoltage or through applying plate voltage too soon after lighting the filaments. Contacts on the motor starter prevent the application of the plate voltage until about 15 seconds after the START switch is thrown for main operation, and a special time delay relay circuit provides this delay when the emergency power is employed.

13. *Maintenance of Equipment.* The commutators and slip rings of the motor generator should be kept clean and free from dirt or grease. In normal maintenance the gentle application of a piece of canvas to the commutator and slip rings occasionally should keep them in good condition. A shiny coffee colored surface which is clean and without grooves or scratches is an indication of a commutator in good condition. In smoothing commutators or slip rings, crocus cloth or fine sandpaper, No. 00 or finer, should be used. *Emery cloth must never be applied to electrical machinery.* The ball bearings should be lubricated about every six months. In greasing the machines, remove the drain plugs on the under side of each bearing. Use only a sodium base grease of light consistency (a tube of grease is furnished with each machine). Do not use an excessive amount of grease. After greasing, run the machine for a little while to remove all pressure on the bearings before replacing the drain plugs. Great care should be taken to keep the grease and bearings clean. Dirt will destroy ball bearings quickly. The bearings should be washed in kerosene, gasoline or carbontetrachloride (Pyrene) and repacked at least once a year. Do not permit grease to reach the brushes, brush-holders, commutators or slip rings. Insure, by occasional inspection, that the brushes are free in the brush holders, removing them and cleaning the sides of the brushes occasionally to prevent binding.

The interior of the transmitter should be kept clean and free from dust. Accumulations of dust and moisture over a long period may cause serious breakdown.

The keying relay, which is located on a bracket at the right side of the transmitter, normally should need no attention over a long period of time. The contacts may occasionally be cleaned by rubbing with a piece of crocus cloth or fine sandpaper. Care should be taken not to bend the contact springs of the relay when cleaning it. The protective relay, located on the same bracket, may need to have its contacts wiped with a piece of crocus cloth occasionally in order to insure that the keying circuit, of which these contacts form a part, is complete. The contacts of the emergency time delay relay, on the transmitter base, should be sanded about twice a year. The starting relays in the terminal box of generator 120A need no attention unless sticking of the contacts is experienced, in which case it will be necessary to sand the contacts.

If at any time the sections of the frequency switch should become sticky in operation, a very slight film of light grease or vaseline may be applied with the fingertips to the switch contacts. In no case should any quantity of grease be allowed to accumulate on the switch, as this could cause short circuiting from contact to contact and erratic performance of the oscillator.

14. *Typical Operating Conditions.* The following data are presented to indicate the meter readings which may be expected at any frequency under normal conditions of operation; using either CW or ICW:

Main Operation

Fil. Volts	Osc. Pl.	Buf. Pl.	Amp. Pl.	Ant. Current
10.3	50 ma	50–120 ma	300–350 ma	(8 to 12 amp., depending upon antenna characteristics)

Emergency Operation

Fil. Volts	Osc. Pl.	Buf. Pl.	Amp. Pl.	Ant. Current
10.3	20 ma	30–50 ma	150	(3 to 4 amp, depending upon antenna characteristics)

CHAPTER 14

LIFEBOAT RADIO EQUIPMENT

For several years, certain passenger vessels have been required by law to carry one or more radio-equipped motor lifeboats. During World War II, the use of such equipment on lifeboats was extended to cargo vessels resulting in a substantial decrease in marine casualties.

The first requisite of each sea rescue is the determination of the location of the lifeboats, even though they may have sailed or drifted miles from the scene of the disaster. This is accomplished through the use of visual signaling devices and radiotelegraphy. The range of the former is limited to the eye, whereas radio equipment can be used to summon aid over distances of hundreds of miles as well as permitting the fixing of location of the radio-equipped boats by direction finders.

Prior to October 31, 1944, radio equipment employed on lifeboats was limited to operation on one radio channel, the international frequency of 500 kc. Battery-powered transmitters, operating on 500 kc, are limited to the ground wave range of approximately 300 miles. Since most seagoing ships are equipped with loop direction finders capable of operating on this frequency, they can locate the radio-equipped lifeboat, and if the other lifeboats hover around the radio equipped lifeboat, rescue of all is assured.

Tests conducted by the U. S. Coast Guard with the co-operation of the land-based Adcock high-frequency direction finding net of the Radio Intelligence Division of the Federal Communications Commission demonstrated that it was possible to fix the location of a lifeboat rapidly and accurately if it was equipped with a high-frequency radio transmitter. This was possible at distances far beyond the ground wave range of the 500-kc frequency.

The report of the Coast Guard, as published in the Proceedings of the Merchant Marine Council, shows the procedure that was followed and is comparable to that which might be followed in any air-sea rescue operations. The report reads, in part, as follows:

> "A high-frequency transmitter, by creating a long-distance sky wave, will give good signals over an area beginning about 300 miles from the set and extending up to 1,500–2,500 miles, depending upon conditions, but its ground wave will be inferior to that on 500 kilocycles. Further, the range of high-frequency transmitters will vary under day and night conditions for different frequencies. To insure complete coverage at all times without 'skip' two differing high frequency bands must be used. With such equipment a boat's signals could be picked up at long ranges by shore direction finders and an area of position established, but since few ships or aircraft have high frequency direction finders, search craft could not make use of these signals.
>
> "To meet the situation Coast Guard communications personnel took a standard SCR-578 transmitter (the Gibson Girl) and modified it so that in addition to transmitting SOS on 500 kilocycles it alternately and automatically broadcast on 4140 and 8280 kilocycles. These three bands practically insure coverage, both day and night, of the complete circle centered at the transmitter and extending as far as 2,500 miles. The modification involved no changes in weight or size of the instrument.
>
> "To test the efficacy of this equipment for its purpose the set was taken aboard a P.C. boat to a point about 200 miles southeast of Cape Hatteras. A 280-foot wire antenna was sent up by means of a kite and the transmitter cranked for half an hour; thereafter signals were sent for 10 minutes every half hour. These signals were picked up by the Radio Intelligence Division of the Federal Communications Commission through its excellent domestic network of high-frequency direction finder monitoring stations. They were teletyped to the plotting room of the Federal Communications Commission in Washington and the resultant fix was transmitted to the Coast Guard. A total of 69 bearings were taken by 15 different monitoring stations. The distances at which the signals were received and the general accuracy of the intercept is graphically shown on the plotting chart. The Coast Guard received the first plot within 20 minutes after transmission was begun.
>
> "On telephonic advices as to the approximate location of the signal, a Coast Guard plane took off from the Elizabeth City base for the 280-mile run to the target. Weather conditions were unfavorable and ceiling low. When still about 200 miles off, the plane first began to receive signals on 500 kilocycles, and when 80 miles away was able to take bearings on her automatic direction finder. The P.C. boat could not see the plane until it was about a mile off and headed so accurately for the boat that the kite antenna had to be reeled in. Ceiling at this time was 300 feet and it is unlikely that the plane could have found the boat except by direction finder."

The Radiomarine Corporation of America model ET–8030 lifeboat radio equipment described in the following paragraphs is typical of one of the equipments designed to operate on both the 500 and 8280 kc channel.

14–1. RMCA Model ET–8030 Lifeboat Transmitter-receiver—The RMCA model ET–8030 is a new type of lifeboat radio equipment which provides two-way radiotelephone and radiotelegraph communication. It also provides one way AUTOMATIC radiotelegraph transmission for use by unskilled personnel. With AUTOMATIC operation, SOS signals and "long dashes" are transmitted. The long dashes enable ship and shore direction finders to take radio bearings for determining the position of the lifeboat.

The radio transmitter operates on 500 kc (600 meters) and 8280 kc (36.2 meters). The radio

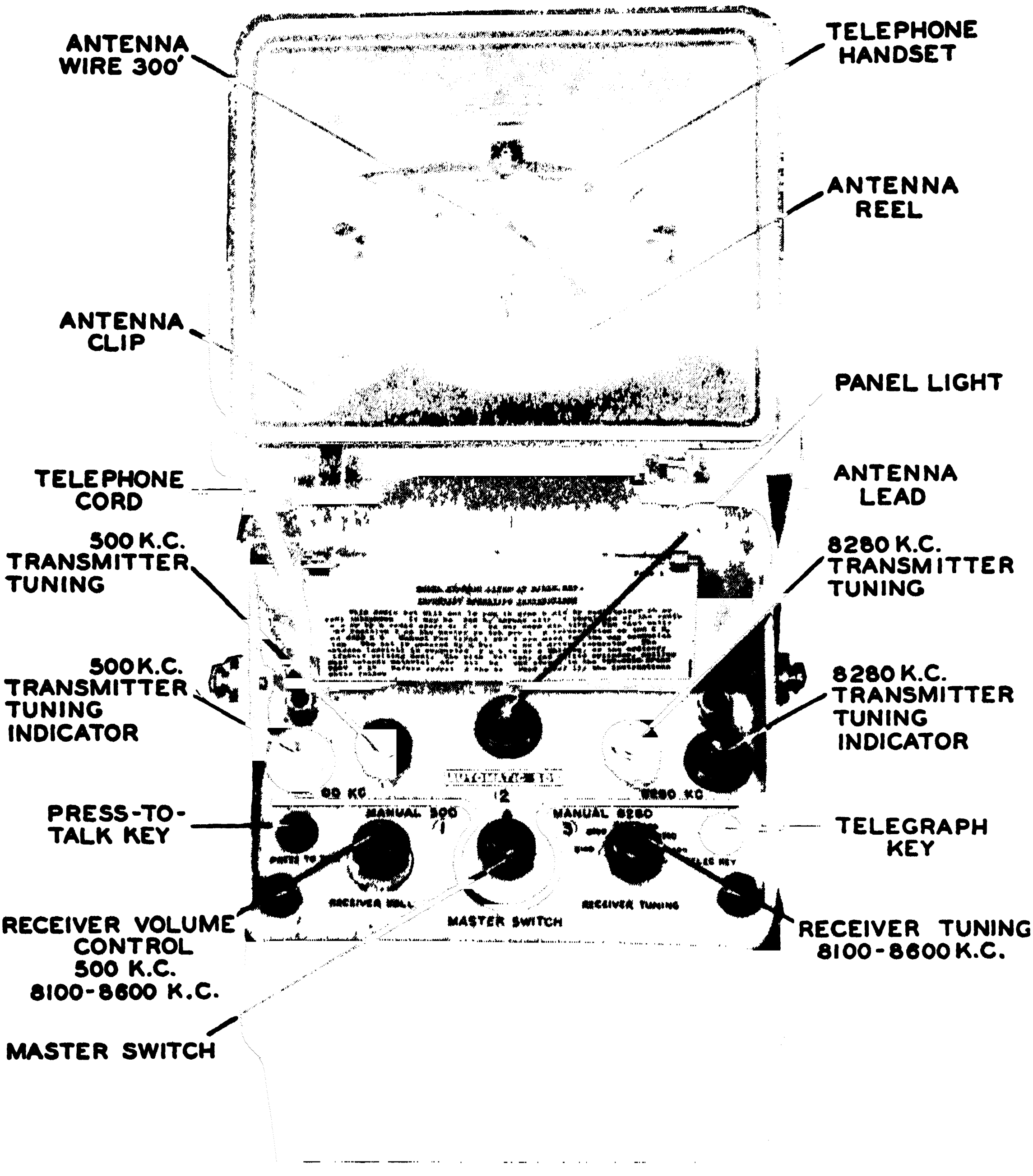

ANTENNA WIRE 300′
TELEPHONE HANDSET
ANTENNA REEL
ANTENNA CLIP
PANEL LIGHT
TELEPHONE CORD
ANTENNA LEAD
500 K.C. TRANSMITTER TUNING
8280 K.C. TRANSMITTER TUNING
500 K.C. TRANSMITTER TUNING INDICATOR
8280 K.C. TRANSMITTER TUNING INDICATOR
PRESS-TO-TALK KEY
TELEGRAPH KEY
RECEIVER VOLUME CONTROL 500 K.C. 8100-8600 K.C.
RECEIVER TUNING 8100-8600 K.C.
MASTER SWITCH
MANUAL 500
MANUAL 8280
MASTER SWITCH

Fig. 14–1. The RMCA model ET-8030 lifeboat radio.

receiver is fixed tuned for 500 kc, and also tunable from 8100 to 8600 kc. For AUTOMATIC operation, only the transmitter functions. For MANUAL operation, both the transmitter and receiver are in circuit for two-way telephone or telegraph communication on either frequency. The 500-kc frequency will provide a range of approximately 50 to 200 miles, while the 8280-kc frequency will provide ranges up to 1000 or 2000 miles or more. Both short and long distance radio direction finder bearings can be taken on the signals transmitted from the lifeboat.

A compact watertight binnacle houses the complete transmitter and receiver, together with a hand-driven generator, a telephone handset, and an antenna reel with 300 feet of wire. The entire equipment is powered by means of a built-in hand driven

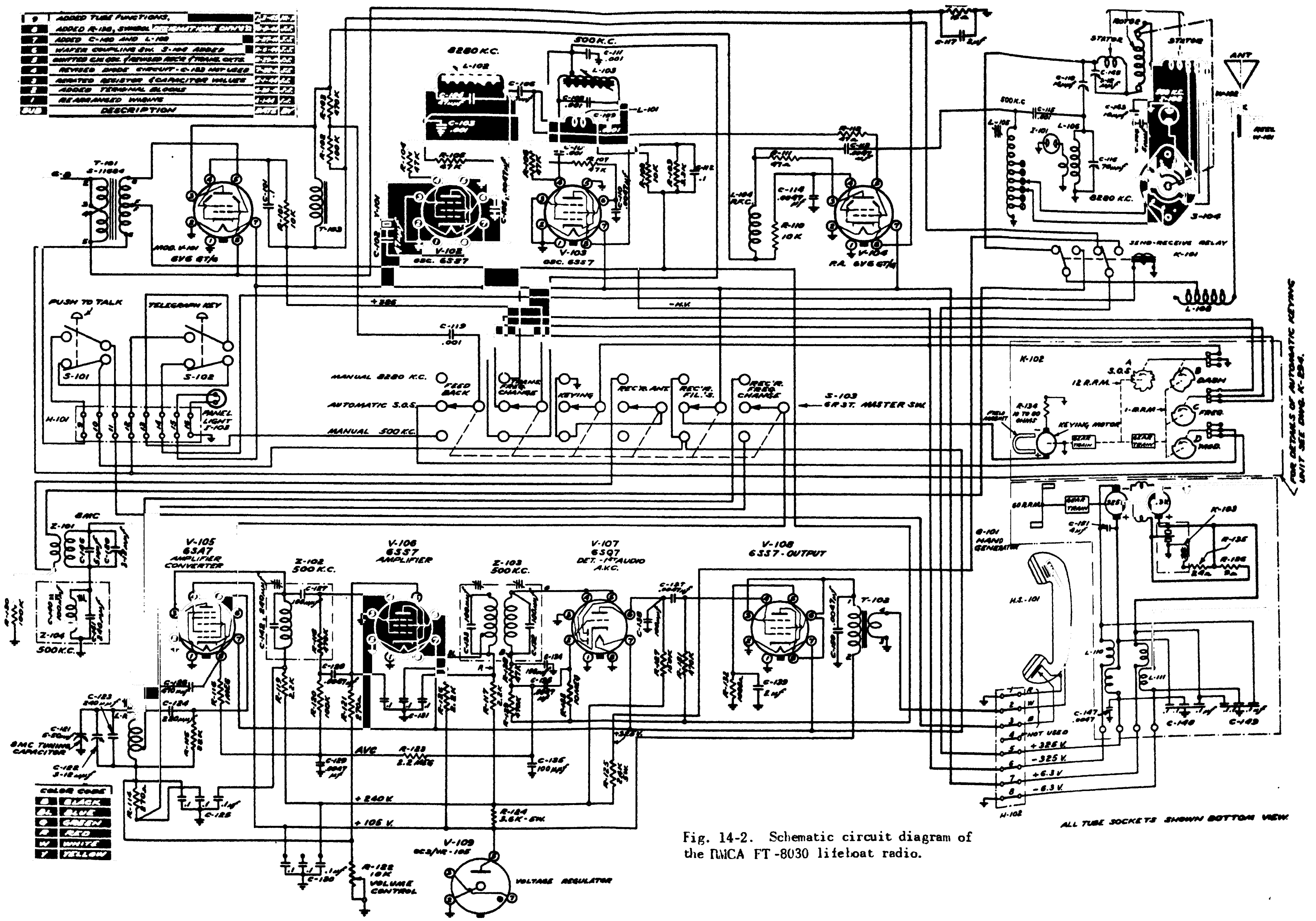


Fig. 14-2. Schematic circuit diagram of the RMCA FT-8030 lifeboat radio.

generator. This generator eliminates the use of all batteries and, therefore, enables the equipment to be used for indefinite periods.

Three types of antenna may be used with the set, namely, a kite-supported antenna, a balloon-supported antenna, or a conventional sailing-mast antenna. The best range and performance is obtained with the kite- or balloon-supported antenna. For wood hull lifeboats, a 20-foot length of wire, with a sinker, is provided for immersion in seawater. On metal hull lifeboats, the set is permanently grounded to the hull.

A watertight metal spare parts box is furnished with each installation for stowage in the lifeboat. This box contains spare tubes and indicator lamps, tools, antenna wire, a kite, a balloon in a sealed metal container, a helium filled cylinder for inflating the balloon, insulators and wire for constructing a sailing mast antenna, and an artificial antenna for test purposes. A water repellent weatherproof canvas cover is furnished to protect the transmitter-receiver binnacle. This cover should be kept in place at all times, except when the equipment is being operated.

14–1a. Circuit Arrangement—Refer to schematic diagram, Figure 14–2, and the various photographs in this book. A correct understanding of the various circuits and their principles of operation is essential to locate troubles and make repairs.

The 500-kc master oscillator for the transmitter is a 6SS7 tube, V–103. The frequency of this oscillator is adjusted by means of the movable iron core in L–103. Do not disturb this adjustment as it is carefully set for 500-kc at the factory.

The 8280 kc oscillator is a 6SS7 tube, V–102, and has its frequency controlled by means of a type R4 crystal, Y–101. The inductor L–102 for this oscillator has a movable iron core which is adjusted at the factory and should not be disturbed. During automatic operation, the frequency cam C on the automatic keying unit, K–102, alternately places plate and screen voltage on the 500-kc and 8280-kc oscillator tubes.

The power amplifier is a 6V6–GT/G tube, V–104. Control grid drive for this tube is taken from the oscillator tank circuits through R–112 as shown on Figure 14–2. The plate circuit of the power amplifier tube is coupled to the 500 kc and 8280 kc tank circuits through C–113. L–105 and C–115 comprise the 500 kc tank circuit. L–106 and C–116 make up the 8280 kc tank circuit. This arrangement permits both tank circuits to function independently without switching.

On 500 kc, the antenna circuit is resonated by means of L–107 (tapped) while the antenna coupling voltage is obtained from taps on L–105. When knob A for 500-kc antenna resonance is rotated, it engages a starwheel which automatically changes the taps on L–107 and L–105. This action takes place when the variometer rotor of L–107 is adjusted. All taps are preset at the factory. On 8280 kc, coupling is obtained from C–118 (preset). Antenna resonance on 8280 kc is maintained by panel-controlled condenser C–116 which tunes the tank circuit to resonance.

The modulator is a 6V6–GT/G tube, V–101. For telephone modulation, the audio input for this tube, from the microphone on the handset, is stepped up by means of transformer T–101. For A2 telegraph modulation in the automatic position and the manual 500 kc position, feedback through C–119 is employed to permit the modulator tube to also function as an audio oscillator. The voltage across reactor T–103 modulates the power amplifier plate and screen circuits.

The automatic keying unit, K–102, uses a 6 volt d-c motor which runs at 900 rpm. This motor drives, through a suitable gear train, four cams identified as A, B, C and D. Cam A, which rotates at 12 rpm, is used to transmit SOS. Cam B, one rpm, controls the long dash by preventing the SOS cam from functioning for approximately 15 second intervals. Cam C changes frequency by applying plate voltage to the 500-kc oscillator for one-half the time and then applying plate voltage to the 8280 kc oscillator for the other half. Cam D controls the modulator feedback circuit in the automatic position so that the signal is modulated on 500 kc and not modulated on 8280 kc.

The hand-driven generator is provided with a built-in a-f and r-f filter, and an automatic voltage regulator as shown in Figure 14–2. Do not disturb the adjustment for the automatic voltage regulator unless absolutely necessary, in which case the armature and contact spacing must be maintained exactly as specified on the inside of the machine cover.

The radio receiver uses four tubes in the r-f, i-f, and a-f circuits, and a voltage regulator tube, as shown in Figure 14–2.

(a) For 500-kc reception, tubes V–105 and V–106 function as r-f amplifiers.

(b) For 8280-kc reception, tube V–105 operates as a pentagrid converter to deliver an intermediate frequency of 500 kc. Under these conditions, the oscillator section of V–105 is tunable from the panel to permit reception of signals between 8100 and 8600 kc.

(c) Tube V–107 functions as a detector and the first audio stage and also provides AVC.

(d) Tube V–108 is the second audio or output tube and delivers its signal to the receiver in the handset through transformer T–102.

(e) The voltage regulator tube V–109 maintains substantially constant the 105 volt supply used by some of the tubes.

(f) Volume control R–122 is connected in the cathode circuits of V–105 and V–106.

FIG 14–3 The RMCA model ET-8030 transmitter-receiver installed in a lifeboat.

The send-receive relay K–101 is a double-throw unit. Operation of this relay is unique in that the relay coil is energized in the "receive" position and de-energized in the "transit" position. This is done to enable the transmitter to function in the automatic position in the event of relay coil failure.

The 500-kc antenna variometer uses condenser C–145 in parallel with one section of the stator. This provides a high-impedance trap circuit for 8280 kc so that power on that frequency is passed on to the "send-receive" relay and not shunted to ground by L–107. A small loading inductor L–108, permanently connected in series with the antenna lead, equalizes 8280-kc loading to the antenna. The 500-kc antenna indicator I–102 is coupled through C–143 and C–144 and also through the capacitance of one of the switch positions to provide proper voltage for the neon lamp. The 8280-kc neon antenna indicator is coupled by means of a small coil to the 8280-kc tank inductor L–106.

The microphone in the handset obtains its voltage from R–113. This resistor carries the cathode current of the modulator and power amplifier tubes. The d-c bias for the control grid on the modulator

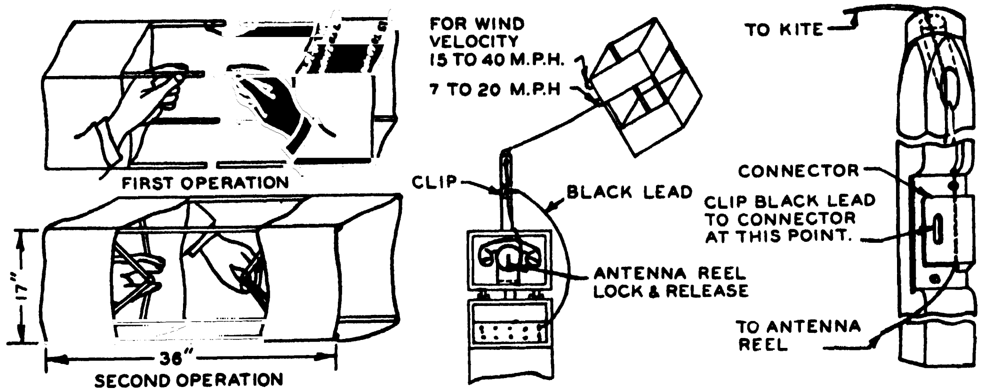


Fig. 14–4. Kite assembly.

tube is obtained from the junction between R–108 and R–109, these two resistors, in series, functioning as the power amplifier grid leak.

14–1b. Antenna Instructions—Always use the kite when wind velocity permits (7 to 40 miles per hour). Use the balloon in calm weather. The balloon can only be inflated once and will remain aloft for about two or three days. With either kite or balloon, use the 300-foot length of wire wound on the bakelite reel in the top hinged cover of the set. For a sailing mast antenna, use the 50-foot length of heavy flexible wire and the three insulators in the spare parts box. Use sailing mast antenna as a last resort because set will give much greater range with the 300-foot kite or balloon antenna.

1. *Kite Assembly* (see Figure 14–4). Assemble the two halves of the kite by pressing together tightly the four tubular supports until they snap into position. The pair tied together by a cord should mate. Next, press outward on the two center spiders until they snap into position slightly beyond dead center. This makes kite fabric taut. Then fasten clasp on end of antenna wire to the lower eye on the kite for light winds, or to the upper eye for strong winds. Toss kite into air to leeward, taking care that it does not foul in the sea. Wetting the kite should be avoided. Allow kite to carry aloft the 300 feet of wire on antenna reel and lock reel. Make sure flexible black wire is clipped to metal connector on antenna support.

2. *Balloon Inflation* (see Figure 14–5). Open sealed container using key soldered to lid. Carefully remove balloon, lay it out lengthwise and avoid tearing. Creases in balloon will clear during inflation. Fasten safety clasp on antenna wire to both cord loops on neck of balloon. Remove rubber safety plug from neck of balloon. Wet inflating nozzle on helium cylinder. Push neck of balloon all the way down on nozzle. Open cylinder valve *very slowly*. Avoid quick rush of gas until diameter of balloon is 18 inches. Then open valve further until all gas is used. Balloon diameter will be about 4 feet. Remove balloon from nozzle, wet rubber safety plug and insert tightly into balloon neck. Send balloon aloft, using all antenna wire on reel. Make sure black lead is clipped to connector on antenna support.

14–1c. Technical Characteristics—The technical characteristics tabulated below are those specified by F.C.C. The ET-8030 equipment equals these requirements:

Oper. Freq. (*kc*)	Frequency Tolerance (%)	Type of Emission	Modulation Percent	Modulation Frequency (*cycles*)	Power Output Long Antenna (*watts*)	Power Output Short Antenna (*watts*)
500	0.5	A2	70 min.	450–1250	5	2
500	0.5	A3	70–100	400–3000	4 (carrier)	1.5 (carrier)
8280	0.02	A1	0	0	4	3
8280	0.02	A3	70–100	400–3000	4 (carrier)	3 (carrier)

1. *Antenna Characteristics.* For power output measurements the long and short antennas referred to above have the following characteristics:

Long antenna:
500 $\mu\mu$f and 15 ohms at 500 kc.
300 ohms (no capacitance) at 8280 kc.
Short antenna:
100 $\mu\mu$f and 10 ohms at 500 kc.
50 ohms (no capacitance) at 8280 kc.

The transmitter output circuit on 500 kc provides sufficient continuous variation of inductance to resonate an antenna of 80 to 750 $\mu\mu$f capacitance and 10 to 20 ohms resistance.

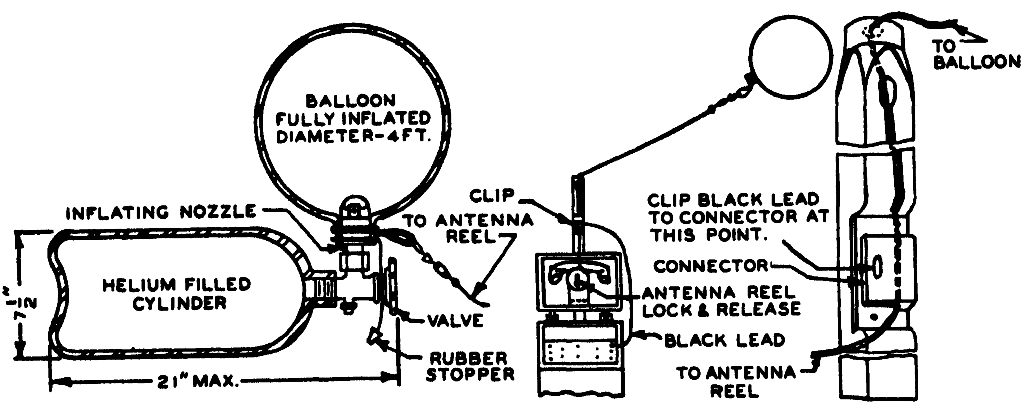


FIG. 14-5. Balloon inflation.

2. *Transmitter Frequency Control.* Pretuned to 500 kc and 8280 kc. Self-excited oscillator for 500 kc. Separate crystal controlled oscillator for 8280 kc.

3. *Keying Characteristics.* The automatic keying device in the transmitter, for an interval of one minute, provides: Three SOS signals for about 15 seconds, a long dash for about 15 seconds, all on 500 kc. Circuits are then switched automatically to 8280 kc and the same sequence of SOS and long dash signals is repeated for approximately the remaining 30 seconds.

4. *Power Supply.* Built-in hand-driven generator, with automatic voltage regulator, a-f and r-f filters, 50 to 70 rpm crank speed, normal speed 60 rpm, delivering 325 volts, .11 amp d.c. and 6.3 volts, 2.5 amp d.c. Maximum horsepower required is .15 h.p.

5. *Receiver Sensitivity.* The radio receiver on 500 kc deliver 6 milliwatts of audio power into an 80-ohm resistor with a signal-to-noise power ratio of 10 to 1 with an input of not more than 25 microvolts modulated 30 percent at 400 cycles. On 8280 kc, the receiver requires not more than 100 microvolts input under similar conditions.

6. *Receiver Selectivity.* The receiver selectivity is at least equal to the following tabulation:

Ratio: Input Voltage Off Resonance to Voltage at Resonance	*Bandwidth 500 kc*	*Bandwidth 8280 kc*
10 (20 DB)	20 kc	30 kc
100 (40 DB)	40 kc	60 kc
1000 (60 DB)	60 kc	90 kc

7. *Receiver Fidelity and Audio Output Power.* The over-all electrical fidelity of the receiver, from a reference frequency of 1000 cycles, does not exceed 4 db for any frequency between 400 and 2000 cycles. The maximum undistorted audio output power is not less than 10 milliwatts.

14-1d. Operation

1. *Generator.* Remove generator cranks at time of raising antenna wire support. Insert cranks in sockets at each side of set. Crank generator *in direction of arrows* at 60 rpm (one revolution each second). For long period operation put one man on each crank. In all cases, the radio set must be adjusted to deliver power to the antenna as outlined in the following paragraphs. To avoid fatigue, follow a regular routine in cranking after set has been placed in operation. For example, when using "Automatic SOS," crank generator for 2 or 3 minutes, then rest for 10 minutes. For details on adjustments for automatic and manual operation, refer to following instructions.

2. *Transmitting Tuning and Automatic Operation.* Have someone crank generator. Place MASTER SWITCH in position 1 (Manual 500). Press TELEG KEY and hold it down. Now carefully rotate knob A until 500 kc neon light shows maximum brightness. This knob normally will turn "hard" at certain points and may be rotated 2½ revolutions while tuning 500 kc. Next place MASTER SWITCH in position 3 (Manual 8280), hold down TELEG KEY and rotate knob B until 8280 kc neon light glows brightest. Knob B rotates only ½ revolution. This completes transmitter tuning. MASTER SWITCH may now be placed in position 2, and AUTOMATIC transmission will take place on 500 kc and 8280 kc.

3. *Manual 500-kc Operation.* Position 1 of the MASTER SWITCH provides 500-kc telephone and telegraph transmission and reception. To telephone use handset, push black PRESS-TO-TALK button while talking and release button to listen. To transmit SOS, use black TELEG KEY button and send three shorts, three longs and three shorts (---———---). To transmit auto alarm signal, use watch with second hand, hold key "down" four seconds, "up" one second, "down" four seconds, "up" one second, etc., for two minutes. Alarm signal is effective only when transmitted on 500 kc.

Receiver is pretuned for 500-kc reception, and the only adjustment is the knob marked RECEIVER VOLUME.

4. *Manual 8280-kc operation.* Position 3 of the MASTER SWITCH provides 8280-kc telephone and

telegraph transmission and reception. Operation is similar to that described for 500 kc, except that the radio receiver may be tuned for signals between 8100 and 8600 kc. Receiver does not respond to A1 (continuous waves) signals. The radio operator will understand that 8280 kc is preferable for long distance communication, or for very short distances, as between lifeboats. Five hundred kc is preferable for medium distances, direction finder bearings by the rescuing ship, etc. Telephone transmission and reception between lifeboats on either 500 kc or 8280 kc is recommended and both frequencies should be tried in making contacts. Carefully adjust RECEIVER TUNING and RECEIVER VOLUME for best results.

14–1e. Testing and Special Instructions—The best time to acquire practice with this set is *before* it may be needed in an emergency. Learn how to adjust the controls by testing with the RM–33 artificial antenna. Explain to other members of the crew how to use the set. A good time to make tests is before or after regular lifeboat drills, when the lifeboat cover is off.

Remember that SOS signals are transmitted in the AUTOMATIC position and such operation should be limited to tests with the artificial antenna.

The artificial antenna unit, type RM–33, will be found in the spare parts box. This unit has brackets so that it may be supported by the hinged cover of the set for test purposes. Connect the heavy black lead from the set to the post of the RM–33 marked ANT. Connect the green lead (GND) on the RM–33 to one of the bright screws used to anchor the crank chains.

Have someone crank the generator in the right direction at 60 rpm. Tubes require about 15 seconds to warm up. Place MASTER SWITCH in position 1 and practice adjusting transmitter tuning knob "A" until 500 kc neon light shows maximum brightness. Knob "A" rotates through two and one-half revolutions. Next, place MASTER SWITCH in position 3 and practice adjusting transmitter tuning knob "B" until 8280-kc neon light is brightest. The white light on the RM–33 artificial antenna will also glow when the transmitter is properly adjusted for both frequencies.

The radio receiver is energized in MANUAL positions 1 and 3. If desired, the artificial antenna may be disconnected and 25 or more feet of wire from the antenna reel may be stretched out to pick up test signals. The flexible black lead should be fastened to connector on antenna support for this test. Do not operate transmitter under these conditions as signals will be radiated.

AUTOMATIC operation using the RM–33 artificial antenna may also be checked. Three SOS signals, followed by a 15-second dash, are transmitted on 500 kc and the circuits are then automatically transferred to 8280 kc for a similar group of signals. This sequence takes place as long as the generator is cranked when the MASTER SWITCH is in the AUTOMATIC position. 500-kc signals are modulated (A2 emission), while 8280-kc signals are continuous waves (A1 emission).

When wind conditions permit, and if the lifeboat is waterborne, practice may be gained in assembling and flying the kite. With a wind force of 3 (gentle breeze 8 to 12 miles per hour), use the lower eye on the kite. Use the upper eye with a wind force of 6 (strong wind 25 to 31 miles per hour).

The helium cylinder contains only enough gas to inflate the balloon *once* and, therefore, the balloon cannot be inflated for tests. Keep the valve on the end of the cylinder hand tight, but do not force the valve as this may damage the valve seat. Review instructions in paragraph 14–1b to understand inflating the balloon for an emergency.

During actual emergency operation, and when using the kite or balloon antenna, always remember to latch the antenna wire under the metal connector on the wood antenna support, and also fasten the flexible black lead from the front panel to the connector. This will allow static charges to drain off through the set when the antenna wire is held in the hand during elevation of the kite or balloon, and also provides a permanent antenna connection when the set is in use.

The reel for the kite or balloon antenna holds 300 feet of flexible wire. Normally, when the kite or balloon is sent aloft, all of the wire should be used and the reel then tightened with the lock provided. If wind conditions prevent the kite from carrying aloft the entire length of wire, let out as much wire as conditions permit. Likewise, if the balloon, after being inflated for considerable time, loses some of its lift, use less than the 300-foot length, if necessary. In all cases be sure to keep the antenna circuit resonated for the particular length of antenna wire in use by carefully adjusting knobs A and B on the panel.

The wood antenna support insulates the antenna wire. It is important to keep this support dry to avoid leakage which cuts down the range of the set. If the support becomes covered with salt spray, it should be wiped off frequently.

When a sailing mast type of antenna is used, as shown in Figure 14–6, the antenna wire on the reel is not used. Instead, erect the antenna with the large wire and the insulators furnished in the spare parts box, feed the lead-in through the top of wood antenna support and clip it directly to the flexible black lead from the set.

When the lifeboat is under sail, or when a canvas spray hood is used, remember that the antenna wire must be kept clear from such objects. Otherwise, wet objects which touch the antenna wire will cause leakage and reduce the effectiveness of the set. Keep an eye on the ground connection. With a wood hull lifeboat, the 20 foot length of ground wire with attached sinker must be kept over the side. With metal hulls, inspect the ground connection to

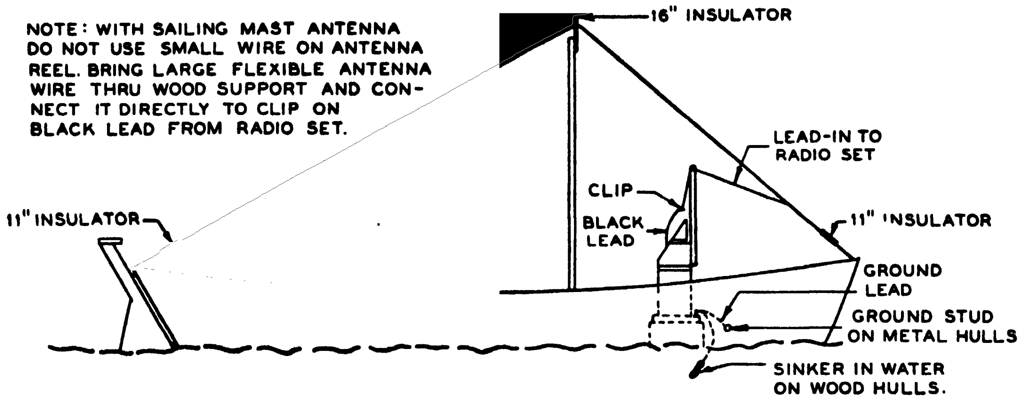

NOTE: WITH SAILING MAST ANTENNA DO NOT USE SMALL WIRE ON ANTENNA REEL. BRING LARGE FLEXIBLE ANTENNA WIRE THRU WOOD SUPPORT AND CONNECT IT DIRECTLY TO CLIP ON BLACK LEAD FROM RADIO SET.
16" INSULATOR
LEAD-IN TO RADIO SET
CLIP
BLACK LEAD
11" INSULATOR
11" INSULATOR
GROUND LEAD
GROUND STUD ON METAL HULLS
SINKER IN WATER ON WOOD HULLS.

FIG. 14–6. Sailing mast antenna.

make sure it is not corroded or broken off. As with any radio set, this equipment needs a suitable antenna and ground connection.

The radio receiver in the set responds to modulated telegraph and telephone signals. When carrying on two way communication, instruct the other station not to use continuous wave (A1) signals.

The purpose of the long dash, transmitted with A2 emission on 500 kc, and with A1 emission on 8280 kc, is to enable ship stations or shore stations to take radio direction finder bearings on the lifeboat.

If the set has been installed on a sub-base, inspect the eight clamping dogs to make sure that they are tight. These dogs hold the bottom of the binnacle to the sub-base.

14–1f. Maintenance

1. *Desiccant Cartridge.* This unit is accessible by removing the pipe plug in the lower rear section of the binnacle. A clamp on the inside of the plug holds a plastic cartridge which is filled with an air-drying material known as silica gel. The cartridge is Ceco part No. 1176 and is marked "AN 4061-1." New unused cartridges are protected from the entrance of air by a red cap cemented on the end. When a new cartridge is placed in the pipe plug clamp, the red cap should be removed and discarded and the cartridge placed in the clamp so that the open end is toward the inside of the set. The silica gel in a new unused cartridge is blue in color. As the material absorbs moisture, it will change in color to pink, indicating the need for replacement. The threads on the pipe plug should be coated with oil or grease, each time the plug is removed, to insure easy replacement and to avoid corrosion. Maintenance personnel are cautioned not to remove the chassis from the binnacle unless absolutely necessary for repairs, as this would disturb the dry air inside.

2. *Generator Lubrication.* The ball bearings in the hand-driven generator are packed with grease for the life of the machine and should not be disturbed. However, a few drops of light oil should be placed periodically in the oil hole above the crank sockets on the outside of the binnacle. Also place a few drops of light oil on the spring inside the two cover clamps.

3. *Binnacle Disassembly.* To repair parts, replace tubes or to remove hand generator, proceed as follows:

(a) Remove the two hexagon bolts in the upper rear corners of binnacle and the two similar bolts in the corners of the front panel. When these four bolts have been removed, the "head" should be lifted straight out so that the entire assembly may be removed from the binnacle. With the hinged cover closed, the assembly may then be inverted and the chassis worked on for repairs or tube replacement.

(b) To remove the chassis completely from the head, unfasten the five flexible couplings and remove the six hexagon bolts inside the head. Disconnect leads from both terminal blocks, the two leads to the indicator lights and the Packard cable antenna lead. This then provides access for removing the hand generator, if necessary.

(c) To remove the generator, free the two angle brackets inside the head, remove both crank socket glands (four hexagon bolts per gland), and then remove the four hexagon bolts from the top center section of the head.

(d) When replacing the generator, care must be taken to insure correct alignment. First tighten the four hexagon bolts in the top of the head. Then carefully tighten the four bolts in each of the crank socket glands. Before these bolts are drawn up tightly, insert the cranks and rotate the machine to check alignment. If the armature does not rotate freely, shift the glands slightly and then tighten. Then fasten the two angle brackets inside the head so that they bear on the cover plate of the generator.

(e) All tubes are held in their sockets by means of circular spring clamps. To remove a tube, press the clamp toward the chassis. All tube sockets are labelled with the correct tube type.

4. *Watertight Seals.* The main rubber gasket between the head and the binnacle should be in good condition. The four hold-down bolts, which seal this gasket, should be drawn up evenly to insure a good seal. Each control shaft has a watertight seal inside the head. The hexagon nuts under the knobs should be kept tight. The seals for the three indicator lights must be tightened from the inside of the head, as well as the seals for the two push button switches. The bushings for the antenna lead and the handset cord may be tightened from the outside.

5. *Painting.* If paint has been scraped from any part of the binnacle or head, new paint should be applied to protect the aluminum parts from corrosion. Direct particular attention to the base of the binnacle and the sub-base, keeping these parts painted where water is apt to accumulate. Also apply a few drops of oil to each of the eight clamps on the sub-base so that the wing nuts turn freely.

14–1g. Service Notes—In servicing the equipment, locating and correcting troubles, and to replace tubes, reference should be made to Figure 14–2 as well as the section covering maintenance. Resistors, inductors, transformers may be checked for continuity by conventional ohmmeter measurements. In checking condensers, the circuit must be analyzed to take into account other elements such as resistors which may be shunted around condensers. Defective tubes or indicator lights may be located by replacing such tubes or lights, one at a time, in their respective sockets.

When the transmitter-receiver chassis is removed from the binnacle for service work, it should be placed on its back so that the controls on the front panel face upward for accessibility. Care should be taken not to damage any of the components when the set is out of the binnacle. Since it is not convenient to crank the generator when the set is on its back, it is possible to use a 6-volt storage battery to drive the generator, at low speeds, as a dynamotor for test purposes. To do this, connect the 6-volt battery with the positive lead on terminal 7 and the negative lead on terminal 8 of terminal block H–102. Do not remove any of the normal leads to the terminal block. A knife switch should be used in series with the battery to turn the power on and off. As a general rule, it will not be necessary to use 6-bolt battery operation unless defective parts cannot be located as outlined above. It is emphasized that service personnel should not disturb any of the factory settings of iron cores, trimmer condensers, etc., unless it is clearly evident that realignment is mandatory. If the transmitter is tested with 6-volt battery supply, the neon indicator lamps may not glow because of the low power obtained under this condition. However, when necessary, the 500-kc oscillator and P.A. tank circuits, the 8280-kc oscillator tank, and the receiver circuits may be aligned as detailed on pp. 607.

Service work which involves transmitter or receiver alignment should preferably be done by removing the equipment to a service shop where adequate test facilities are available. If the work must be done aboard ship, test signals for the receiver on 500 kc and 8280 kc may be obtained by running the appropriate shipboard transmitter on low power with the transmitter antenna disconnected. If this is done, great care should be exercised not to overload as the circuits cannot be peaked if the signals are too strong. Receiver alignment on 500 kc should be performed first, using a weak modulated signal and keeping the receiver volume control adjusted to prevent overload. The 500-kc r-f input for the receiver is peaked by adjusting carefully the iron core in Z–104. Then peak the amplifier circuits by adjusting the iron core in Z–102 and both iron cores in Z–103. This completes 500-kc receiver adjustments.

To align the receiver using a weak modulated 8280-kc signal, first tune the signal with the tuning control on the front panel. Then, keeping volume low, adjust C–120 in the 8-mc r-f input unit Z–101. The white dot on the receiver tuning knob for an 8280-kc signal should indicate resonance when it is slightly below the 8300-kc calibrated point. If this condition is not obtained, place the white dot on 8600 kc, using 8600-kc signal, and adjust C–122. Then set white dot on 8100 kc, use an 8100-kc signal and adjust iron core in L–109. Manual position 1 (500 kc) or manual position 3 (8280 kc) of the MASTER SWITCH should be used as required when aligning the receiver and transmitter.

To adjust the 500-kc master oscillator in the transmitter using an accurate frequency meter, move the iron core in L–103 until the correct frequency is obtained. When this adjustment is made, the 500-kc P.A. tank inductor, L–105, must be kept in resonance by means of its iron core, and the transmitter loaded out into the artificial antenna.

To adjust the 8280-kc crystal-controlled oscillator, a 0–25 volt d-c voltmeter should be temporarily connected across R–109. The voltmeter will then read a portion of the rectified P.A. d-c grid voltage. Then adjust the iron core in L–102 for maximum voltage. Under these conditions, the 8280-kc P.A. tank should be kept in resonance by adjusting front panel control C–116, and the transmitter loaded out into the artificial antenna. For both 500-kc and 8280-kc transmitter adjustments, use the local shipboard receiver to check telephone modulation and telegraphic keying.

If transmitter operation is normal with both manual positions of the MASTER SWITCH and if the correct sequence of operation is not obtained in the AUTOMATIC position, the keying unit K–102 should be inspected. If the keying motor is not rotating, the four cams will have stopped at some point and no automatic sequence will take place. Remove the commutator cover of the keying motor, inspect commutator and brushes, and carefully clean or adjust, if necessary. These parts have small dimensions and extreme care must be exercised not to damage them while cleaning. With the motor running, the follower which slides on each cam should operate freely to insure positive action of the microswitches actuated by the followers. A single drop of light oil may be placed on each cam and on the exposed shafts and gearing. Do not disturb or lubricate the sealed gear train of the keying unit. Correct motor speed may be checked by noting that the SOS cam makes one revolution in approximately 5 seconds, or the other three cams make one revolution in approximately 60 seconds.

Before reassembly of the units in the binnacle, check that all terminal board connections are tight, tubes held firmly in their sockets by the clamps, crystal clamped tight, and all set screws on flexible couplings and other shafts properly fastened. Also replace the desiccant cartridge, if the silica gel is pink in color.

14–1h. Compliance with Government Regulations—The model ET–8030 lifeboat radio equipment was approved by the Federal Communications Commission on December 29th, 1944, for compliance with the requirements of section 8.210(b) and with an over-all weight not to exceed 160 pounds, including a 35-pound shatterproof type of helium gas cylinder.

Accessory equipment outlined below has also been approved by the Federal Communications Commission and the U. S. Coast Guard:

1. Dewey and Almy Chemical Company, Darex type N–4 neoprene balloon in nitrogen filled sealed container.
2. Radiomarine Corporation of America, type RM–35 nonshatterable helium cylinder, manufactured by the Harrisburg Steel Corporation.
3. Hoffman Radio Corporation, part No. M–357–A, collapsible, box type kite having dimensions of 17 by 17 by 36 inches when ready to fly.

The model ET–8030 lifeboat radio equipment also complies with the requirements of the U. S. Maritime Commission.

14–1i. Note Regarding Balloon—The Darex type N–4 balloon is packed in a metal can 5⅛ inches high and 4¼ inches diameter. When the balloon is packed in the can at the factory, it is hermetically sealed and a small amount of nitrogen gas is placed in the can, under pressure, to protect the neoprene rubber from deterioration. The balloon itself weighs about 11 ounces. Balloon diameter when not inflated is 36 inches. When fully inflated from the type RM–35 helium cylinder, the balloon diameter is about 48 inches. The balloon will not burst until a diameter of approximately 96 inches is reached. A can opener "key" is soldered to the top of the can. This key fits the sealing strip for removal of the can cover.

A new balloon is white in color. After exposure to the sun (as in normal use), the color changes to brown. When inflated to 48-inch diameter, the balloon will lift a weight of about 20 ounces. Since the 300 feet of wire furnished on the antenna reel weighs 11 ounces, it will be apparent that an excess lifting capacity of 9 ounces is available. This is to take care of moderate wind pressure and the gradual loss of lift which takes place from diffusion of the gas while the balloon is aloft. The balloon will fly, even in hot sunlight, for a period of several days, losing lift at the rate of about one-tenth to two-tenths of an ounce per hour.

The balloon has an internal self-closing valve. When the inflating nozzle on the helium cylinder is pushed through the neck of the balloon, it opens the internal valve. When the nozzle is withdrawn, the valve closes. For additional safety, to prevent leakage of gas, the rubber stopper plug should be tightly inserted in the neck of the balloon. If the neck of the balloon is not pushed down over the full length of the inflating nozzle, the internal balloon valve will open due to the high gas pressure and a loud whistle will be produced while the balloon is being inflated.

14–1j. Note Regarding Helium-filled Cylinder—The type RM–35 helium-filled cylinder and valve assembly is approximately 21 inches long and 7½ inches in diameter. Weight is about 35 pounds. The helium gas in this cylinder is colorless, odorless, noninflammable, and nontoxic. However, it must be understood that the gas in the cylinder is under high pressure, approximately 2000 pounds per square inch, and for this reason the cylinder valve should not be tampered with, and the valve only opened when a balloon is to be inflated or when the gas pressure is to be checked.

RM–35 cylinders are shipped with a gas-tight cap nut on the valve outlet. After the ET–8030 installation has been completed, the cap nut is to be removed and replaced by the inflating nozzle, taking care to tighten the nozzle nut properly. Note that cap nut and inflating nozzle nut use left hand threads, and therefore, must be turned to the *right* to remove. The cap nut should always be tightly fastened to the valve outlet whenever cylinders are shipped for refilling or replacement. Both the cap nut and inflating nozzle are chain fastened to the valve to prevent loss. For checking gas pressure, the inflating nozzle is to be removed and a pressure gauge fastened in its place temporarily. *Caution:* Always keep cylinder valve closed when installing or removing cap nut or inflating nozzle.

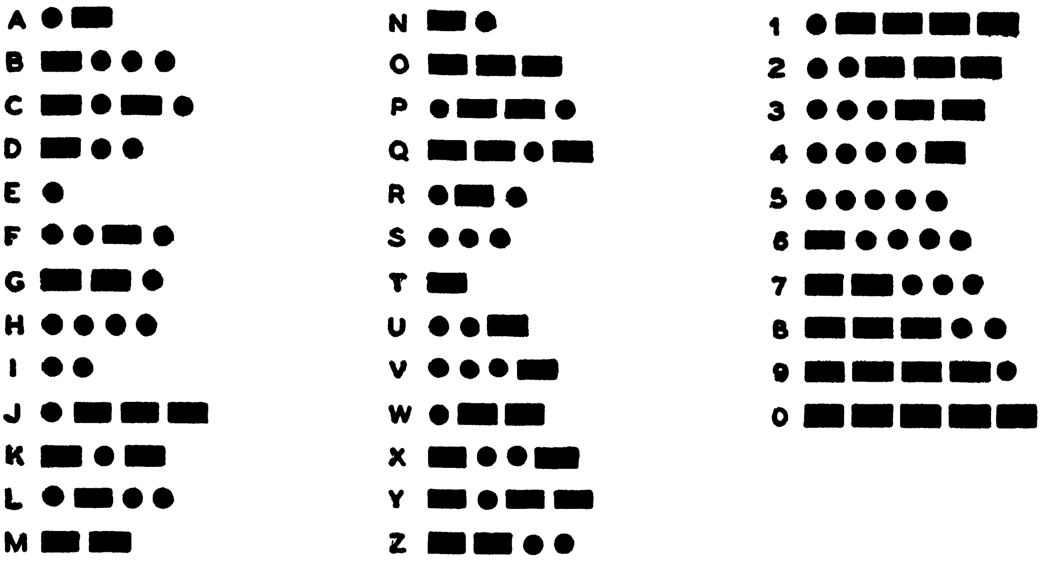


FIG. 14–7. International Morse Code.

As the cylinder is discharged during inflation of the balloon, the cylinder temperature will drop and the cylinder will become quite cold to the touch. This is normal. To protect the cylinder from excessive pressure, due to high temperatures (in the event of a fire near the cylinder), the valve is provided with a fusible safety plug which will melt and release the gas pressure under such conditions. The cylinder itself is constructed of shatterproof steel alloy as an additional safety precaution.

14–1k. Note Regarding Kite—The M-357-A kite weighs about 13 ounces and is stowed in a collapsed form in the spare parts box. When assembled, the kite is approximately 17 by 17 by 36 inches. Flotation pockets are built into the kite fabric so that it is buoyant in case it falls into the sea.

If the kite is tested and the fabric becomes wet or damp as a result of the test, care should be taken to dry the unit before it is disassembled and repacked in the spare parts box.

14–2. RMCA Model ET–8022–C Lifeboat Transmitter-receiver—The ET–8022–C lifeboat equipment comprises two major units. One unit consists of a compact transmitter and receiver mounted in a watertight cabinet and provided with a watertight door which may be opened for access to the controls. The second unit is a small hand driven generator which furnishes the power required by the transmitter-receiver unit, thereby eliminating all batteries or other sources of power supply. The hand driven generator is provided with crank handles so that one or two persons may readily rotate the machine. The hand driven generator is provided with built-in gearing so that when the cranks are turned at a speed of approximately once per second (60 rpm), the generator armature rotates at high speed to produce the necessary voltages. The generator also includes an automatic voltage regulator so that exact speed of rotation of the crank handles is not required.

One of the most important features of the ET–8022–C is the provision for both radiotelephone and radiotelegraph communication. This means that, in an emergency, any layman may operate the set as a telephone transmitter and may broadcast by voice to summon aid. Where two or more lifeboats are equipped with this apparatus, they may keep in contact with one another by direct two way voice communication. The provision for radiotelegraph enables the radio operator or anyone familiar with the code to exchange telegraph signals with other vessels. The equipment may also be used by anyone to transmit continuous telephone or telegraph signals to enable rescuing vessels equipped with radio direction finders to locate the lifeboat.

14–2a. Technical Characteristics

1. *Power Output.* The radio transmitter is designed to deliver approximately 3 to 4 watts of net antenna power, exclusive of all set losses, when operating into an antenna having a resistance of 10 ohms and a capacitance of 100 $\mu\mu$f. Tests made with a typical installation have disclosed that, under normal conditions, a telephone communication range of 25 to 50 miles and a telegraph range of 50 to 100 miles may be expected.

2. *Frequency.* The radio transmitter and receiver are pre-tuned to the international distress frequency of 500 kc (600 meters).

3. *Frequency Control.* The transmitter uses a master oscillator-power amplifier type of circuit to provide a frequency tolerance within plus or minus 0.3 percent.

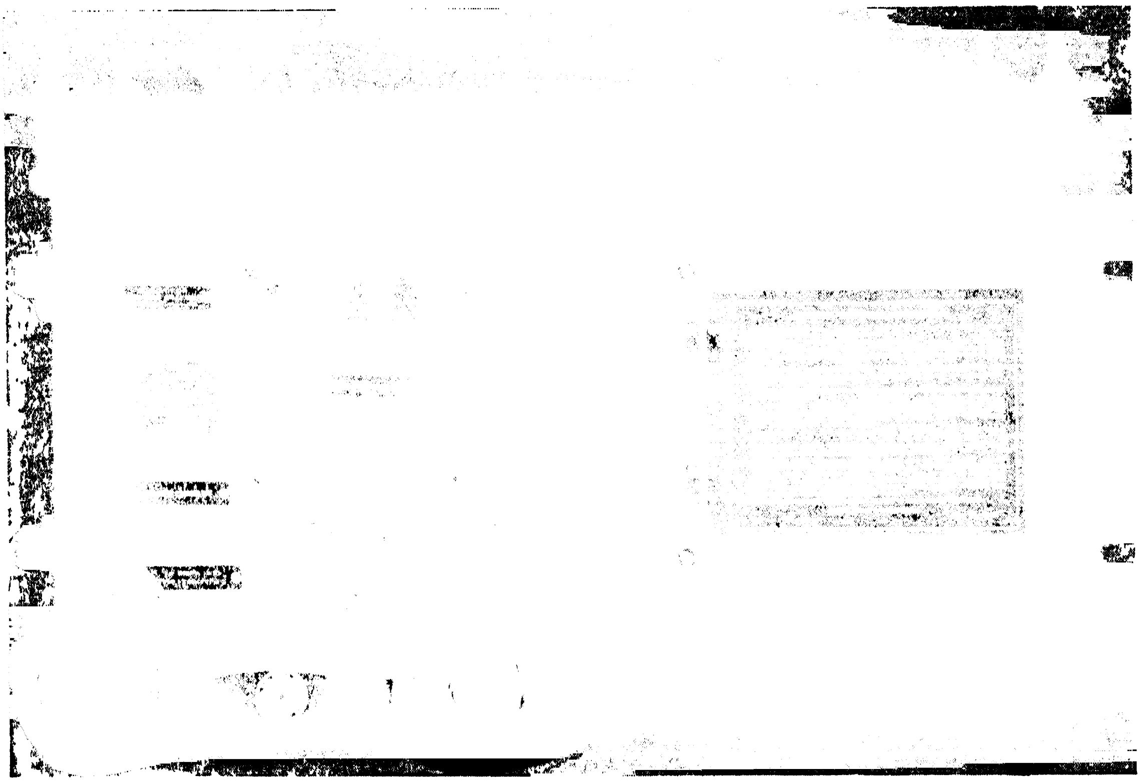


FIG. 14–8. The transmitter-receiver unit of the RMCA model ET-8022-C lifeboat radio.

4. *Modulation.* For telephone transmission, A3 modulation with 100-percent modulation of the carrier wave may be obtained. For telegraph transmission, when the key is closed, the modulator tubes function as self-excited audio oscillators and modulate the carrier wave in excess of 100 percent for positive peaks at an audio frequency between 500 and 900 cycles. This provides a relatively broad telegraph signal desirable for calling other vessels.

5. *Antenna Characteristics.* The transmitter is designed to load into any antenna having a capacitance from 60 to 600 $\mu\mu$f and a resistance from 4 to 10 ohms.

6. *Antenna Construction.* Refer to Figure 14–10 for details of antenna construction.

In all cases, the masts must be of wood and not metal. If guys are used on the masts, they must be made of rope since metallic guys will greatly reduce the effectiveness of the antenna.

7. *Hand-driven Generator Rating.* The hand-driven generator is a double voltage unit designed to deliver 6.3 volts and 3.6 amp for filament supply, and 315 volts, 200 ma, for plate supply.

8. *Automatic Keying Mechanism.* The automatic keying mechanism comprises a small 6-volt motor and a gear train which operates a keying wheel. This wheel transmits SOS three times and a long dash for each revolution. The keyer motor runs at all times when the hand-driven generator is cranked and when the MANUAL-AUTOMATIC switch is placed in the AUTOMATIC position. This arrangement, therefore, enables anyone not familiar with the code to transmit SOS and long dashes by following the instruction card.

14–2b. Transmitter Adjustments—The oscillator adjustment for the transmitter, for setting on 500 kc, is the iron-core coil mounted vertically to the left of the terminal board. The iron core in this coil has been carefully adjusted in the laboratory for 500 kc, and normally should not be altered. If, however, it is ever necessary to adjust the frequency, this is done by using an accurate frequency meter and moving the core up or down, after which it should be locked with the hex nut on the core shaft.

The power amplifier tank inductor is a unit mounted near the center of the front panel with the shaft of the adjustable iron core projecting through the front panel. This coil likewise is adjusted in the laboratory and should not be disturbed until additional adjustments have been made of antenna coupling and antenna tuning, as outlined below.

With antenna erected and the hand driven generator in operation, it is necessary to select the proper tap on the antenna loading inductor and the proper position for the coupling switch. Place the cou-

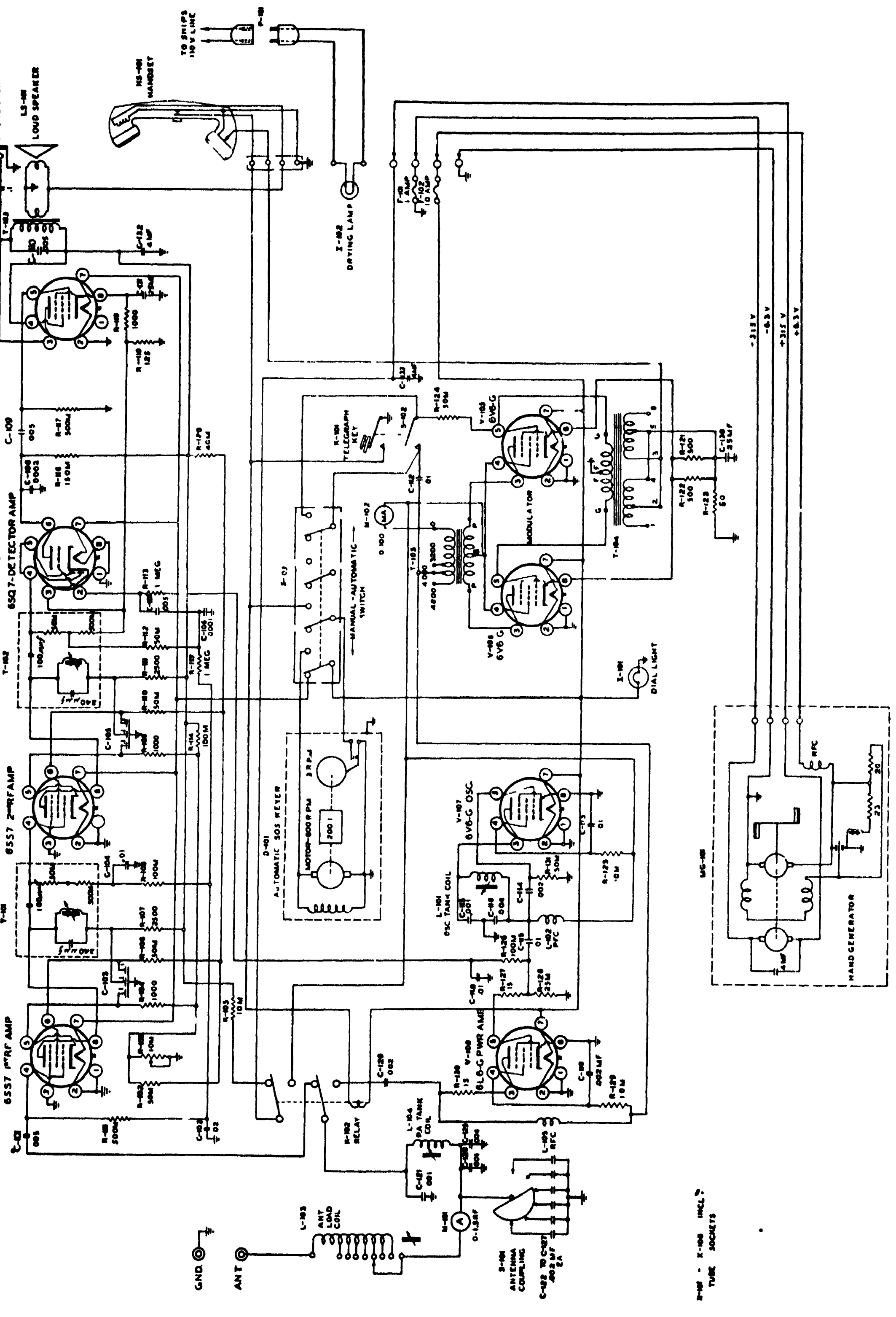


FIG. 14-9 Schematic circuit diagram of RMCA ET-8012-C lifeboat radio.

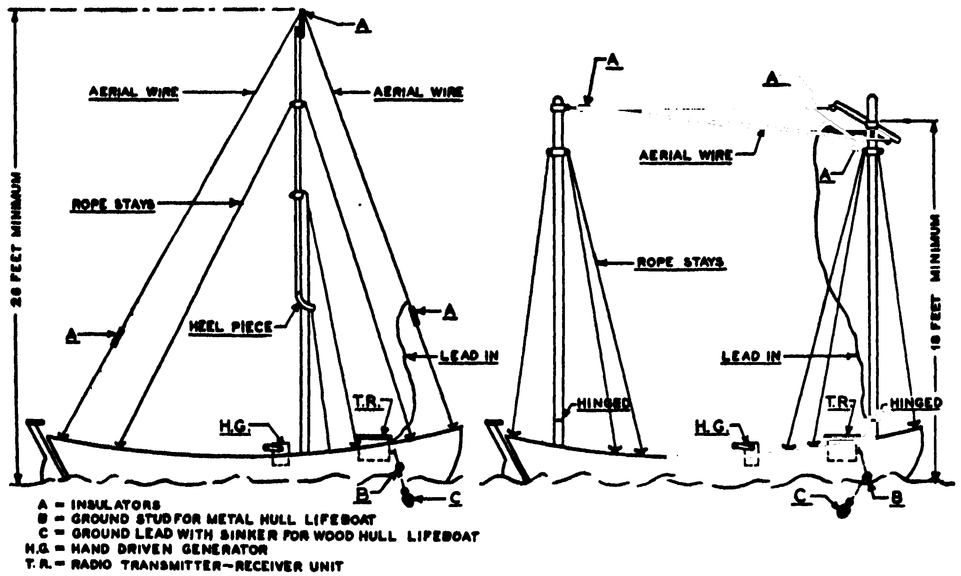


Fig. 14–10. Antenna arrangement for the RMCA model ET-8022-C lifeboat radio.

pling switch at position 3 for a preliminary adjustment. Locate the flexible lead on one of the taps of the antenna load coil, close the push button on the handset, and adjust the antenna tuning knob for maximum antenna current. The movement of the adjustable iron cores in the antenna load coil is a maximum of 1⅝ inches. This corresponds to 53 complete revolutions of the tuning knob. It is very important to select a tap on the antenna load coil which requires the core to be approximately half way in for antenna resonance. This is to provide plenty of leeway of antenna tuning under service conditions where the capacity of the aerial may be a little more or less than the capacity at the time the set is installed and adjusted. In other words, the *correct* antenna load coil tap should be the one which permits the tuning knob to be rotated at least 15 to 25 revolutions in either direction from resonance.

The power amplifier plate current, antenna coupling, and a retrimming of the P.A. tank core should now be checked. The correct value of P.A. plate current as read on the panel meter, with the antenna resonated, should be approximately 50 to 60 ma. The seven-position coupling switch marked "0–1–2–3–4–5–6" is wired so that antenna coupling is *increased* if the switch is adjusted to lower numbers, while it is *decreased* if the switch is adjusted to higher numbers. Therefore, if the P.A. plate current is less than 50 ma, try positions 0–1–2 or 3 on the coupling switch. If the plate current is more than 60 ma, try positions 3–4–5 or 6. When the correct coupling switch position has been determined, disconnect the antenna, loosen the hex locknut on the P.A. core shaft (to the right of antenna meter) and then carefully move the core in or out a little until the plate meter reads the lowest value. Minimum P.A. plate current under this condition will be approximately 25 ma. Then lock the P.A. shaft, reconnect antenna, resonate antenna for maximum current and check P.A. plate current and the antenna coupling switch position to note that approximately 50 to 60 ma plate current is obtained. The point to keep in mind is that readjustment of antenna coupling slightly detunes the P.A. tank circuit requiring a readjustment of the latter, if antenna coupling is changed.

Make all transmitter adjustments with the MANUAL-AUTOMATIC switch in the MANUAL position.

The transmitter should then be checked for modulation by whistling into the microphone and noting that the antenna current increases by approximately 15 percent. Telegraph operation should then be checked by closing the key which produces a modulated signal. Antenna current will, therefore, be higher when the telegraph key is closed than it is with the handset push button closed, with no speech into the microphone.

The telegraph key is mounted on the chassis in such a manner that the moving arm of the key actuates a "micro" switch. This switch is a single-pole single-throw unit which functions with a very small movement of its operating plunger so that the initial movement of the key arm closes the "micro" switch contacts first, after which the normal key contacts close. The "micro" switch contacts close a feedback circuit on the two 6V6G modulator tubes enabling these tubes to function simultaneously as audio oscillators and modulators for A2 telegraph emission. Therefore, it is very important to maintain a correct adjustment of the telegraph key so that when the key is not depressed the "micro" switch contacts are open, while when the key is closed the "micro" switch contacts first make and then the regular key contacts make. If the moving arm of the key is adjusted too close, the "micro" switch would be permanently closed, thereby causing the 6V6G modulator tubes to oscillate continuously, which would prevent telephone communication. Correct adjustment of the key may be checked by noting a slight "click" as soon as the key knob is depressed a little, further travel of the key knob then closing the regular key contacts.

The send-receive relay in the unit is actuated either by the handset push button or by the telegraph key regular contacts. This relay is equivalent to double-pole double-throw, one pole of which transfers the antenna circuit to the receiver or transmitter, while the other pole transfers the 315-volt generator circuit to either the transmitter or receiver. Contacts of this relay should be kept properly adjusted and cleaned so that the relay makes good contact in both the transmit and receive positions.

14–2c. Receiver Adjustments—Normally no adjustments of any nature should be made to the radio receiver circuits, as all circuits are properly lined up in the laboratory.

A special input circuit to the first r-f amplifier in the receiver is used. This input circuit is the transmitter power amplifier tank circuit which is so connected that once the p-a tank circuit is properly adjusted for the transmitter, it is automatically adjusted for 500-kc receiver input.

The plate circuit of the first r-f amplifier and, likewise, the plate circuit of the second r-f amplifier are tuned by means of an adjustable iron core in a parallel resonance circuit as may be seen from Figure 14–9. Since the receiver is a tuned radio frequency unit, the adjustable iron cores of each parallel resonance circuit are adjusted in the laboratory using a low input signal for maximum receiver audio output. Do not readjust these units, unless it is apparent that the receiver sensitivity is low, and, if adjustments are made, they should be done with a steady 500-kc modulated signal and a low adjustment of the volume control.

14–3. Mackay Portable Emergency Marine Radio Transmitter 168B—The Mackay 168B radio transmitter is a portable emergency equipment designed expressly to meet the requirements of the Federal Communications Commission. It complies in all respects to Rules 8.209 and 8.210 of the Fed-

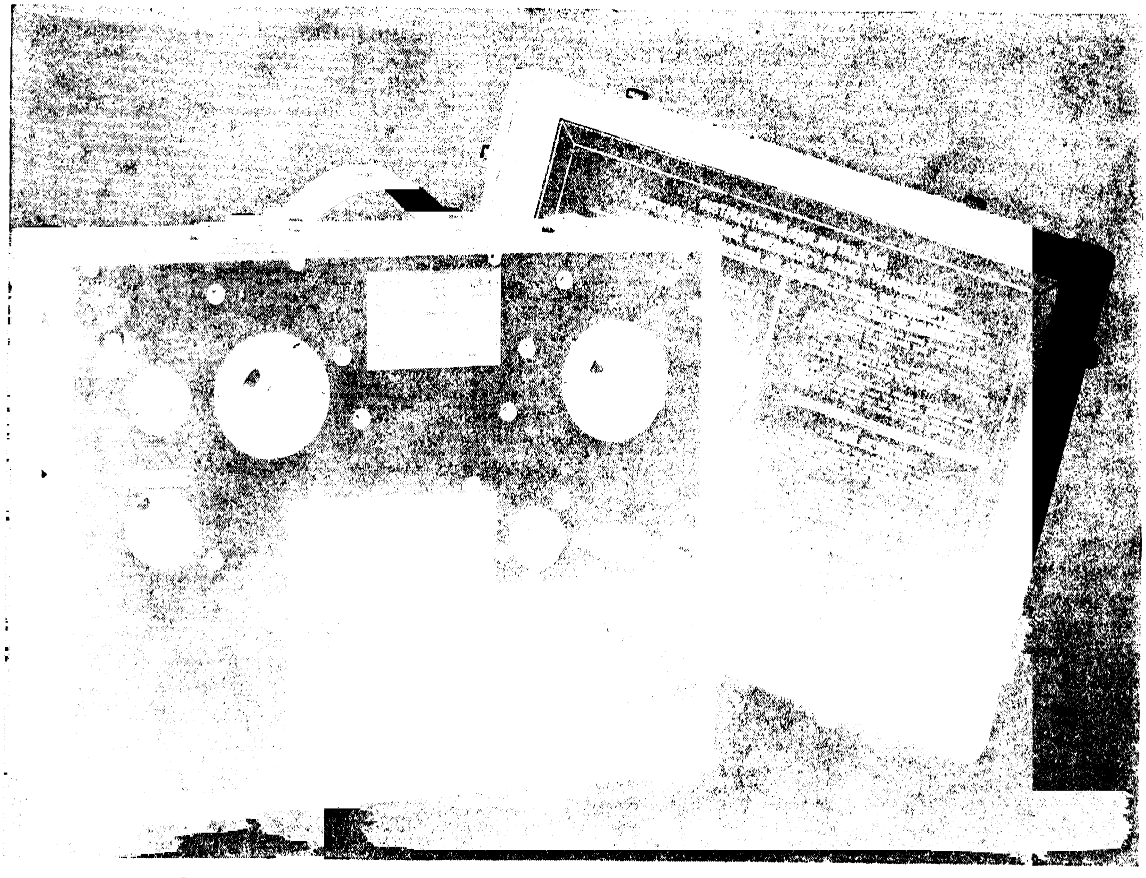


Fig. 14–11. The Mackay model 168B portable emergency marine radio transmitter.

eral Communications Commission relating to portable lifeboat equipment.

The equipment is intended to be stored aboard a vessel in some location where it is available for immediate removal to a lifeboat or similar craft. The transmitter is complete with power supply battery, antenna wire and insulators, grounding lead, dummy antenna and essential spare parts. It is fully automatic in operation and transmits the international "SOS" distress signal for approximately two minutes after the "Start" button is depressed. Furthermore, the distress characters are interspersed with long dashes to permit rescue vessels to obtain radio bearings.

The transmitter output is 5 watts, which is based on a typical antenna of 100-$\mu\mu$f capacitance and 10 ohms resistance, on the distress frequency of 500 kc. The emitted signal is highly modulated, producing a tone of about 900 cycles.

An outstanding feature of the circuit employed is a master oscillator-power amplifier which results in excellent signal characteristics and good stability even though the antenna is swinging considerably. The oscillator-amplifier circuit also possesses the advantage of permitting the equipment to be operated with a wide variety of antennas without internal adjustments. Operation is possible into practically any type of small antenna as may be found possible to erect in a lifeboat or similar craft. This transmitter may also be used with a temporary antenna aboard ship should the regular radio apparatus be rendered inoperative or the ship's antenna equipment be destroyed.

Either the automatic distress signal may be employed, or the key may be used to transmit conventional telegraph signals. The power supply battery permits hourly operations of one cycle (two minutes duration) for a period of at least 48 hours. The equipment is contained in a watertight carrying case. With the cover removed, the internal apparatus is made splash proof by the use of suitable gasketing of controls and panel mounted equipment. The total weight is approximately 60 pounds. All components have been chosen to provide light weight, compactness and durability.

The case which houses the equipment is constructed of laminated wood approximately 21¼ inches long, 16¼ high and 9⅜ inches deep, suitably treated to render it impervious to water and to insure ample buoyancy. Rubber gaskets and valences are employed not only to make the equipment watertight but to enable it to withstand the rigors of actual immersion. Draw bolt baggage clips are used to attach the cover. A split handle is provided on the top side of the case to permit the equipment to be carried by either one or two persons. All corners are reinforced with metal fittings.

14–3a. Arrangement of Components—All of the electrical parts and controls which comprise the circuits of this equipment, with the exception of the storage battery and antenna material and spare parts, are mounted on a single detachable panel. All controls are equipped with rubber gaskets so as to render the equipment splash proof without the cover.

Figure 14–11 shows the appearance of the equipment with the cover removed. The storage battery fits into a compartment in the lower center of the case, at which point the weight is balanced, facilitating carrying and promoting buoyancy. Rubber strips attached to the sides of the compartment prevent the battery from becoming damaged as a result of rough handling. To the right of the battery is another compartment containing the antenna equipment and replaceable spare parts.

The controls, which are attached to the removable panel, consist of the following:

At the right center is a three-position switch labeled KEYING SELECTOR. This switch also permits the hand key, which is placed directly below the KEYING SELECTOR switch, to be used.

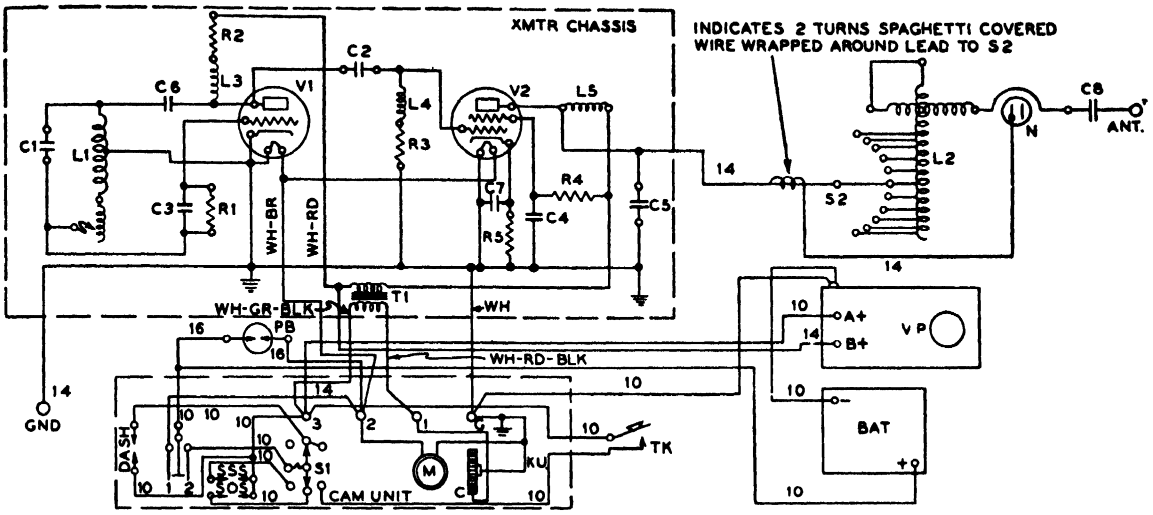
To the left of the key is the START button, which places the equipment in operation for two minutes.

On the upper portion of the panel, to the left of center, is a knob marked ANTENNA SELECTOR. This is a switch which is used to select the necessary inductance for tuning the antenna. Accurate adjustment of the antenna circuit is accomplished by the control at the left of the panel labeled ANTENNA TUNING. Above this knob is a window through which the neon resonance indicating lamp is observed.

The ground lead is attached to the terminal at the lower right marked GROUND, while an insulated terminal at the top left of the panel, marked ANTENNA, is for connecting the end of the antenna wire.

14–3b. Antenna Equipment—Within the compartment at the lower right of the case, is a roll of flexible copper ribbon with an attached weight. This is the ground lead, one end of which is connected to the ground terminal on the panel. To establish a ground connection the weighted end is dropped into the water. A roll of rubber covered, flexible wire is furnished for the antenna, together with three insulators and suitable fittings.

The antenna must be of certain electrical characteristics, but the flexibility of the equipment is such that almost any length or height of antenna can be used. An oar, placed upright in a lifeboat, with the wire strung from its top to one end of the boat and thence to the equipment, will work quite well, although generally speaking, the greater the height of the antenna, the greater will be the range of operation. For all practical purposes, therefore, the antenna most effective must necessarily be one which has a height and length as great as conditions will permit. The antenna prescribed by the Federal Comunications Commission for use with this equipment will provide highly satisfactory operation.



WHEN ORDERING REPLACEMENT VIBRATOR SPECIFY NAME OF MANUFACTURER AND TYPE NUMBER MARKED ON UNIT TO BE REPLACED

TABLE OF REPLACEABLE PARTS

REF NO	NAME OF PART	DESCRIPTION OF PARTS	REF NO	NAME OF PART	DESCRIPTION OF PARTS	REF NO.	NAME OF PART	DESCRIPTION OF PARTS
C 1	CONDENSOR	002MFD 1000V TEST	R 4	RESISTOR	5,000 OHM 10 WATT	VP	VIBRAPACK	SYNCHRONOUS VIBRAPACK
C 2	"	001 " " "	R 5	"	250 OHM 20 WATT			6V INPUT 400V DC AT.1AMP.
C 3	"	001 " " "	L 1	COIL	OSC PLATE COIL			WITH CAPACITY OUTPUT
C 4	"	002 " " "	L 2	"	ANT. LOADING & TUNING	S 1	SWITCH	KEYING SELECTOR SWITCH
C 5	"	001 " " "	L 3	CHOKE COIL	OSC-PLATE CHOKE	S 2	"	ANT
C 6	"	004 " " "	L 4	" "	P A GRID CHOKE	KU	KEYING UNIT	MOTOR-CAM-COMMUTATOR
C 7	"	02 " " "	L 5	" "	P A PLATE CHOKE			ASSEMBLY
C 8	"	01 " " "	T 1	TRANSFORMER	PRI. 6V. SEC 250V AT 1 AMP	PB	PUSHBUTTON	SINGLE NORMALLY OPEN
R 1	RESISTOR	10,000 OHM 1 WATT			TO OPERATE WITH 500	N	NEON LAMP	1/4 WATT CANDELABRA BASE
		INSULATED CARBON			CYCLE CHOPPER	TK	TELEGRAPH	BAKELITE FRAME
R 2	RESISTOR	20,000 OHM 10 WATT	M	MOTOR	6 V D C		KEY	
R 3	"	25,000 OHM 1 WATT CARBON	V 1	TUBE	6J5 OR 6C5 METAL TUBE	BAT	BATTERY	20AH BATTERY, SPILLPROOF
		INSULATED	V 2	"	6L6 " "			VENTS ENTIRELY ENCLOSED

FIG. 14-12. Schematic circuit diagram of the Mackay portable emergency marine radio transmitter model 168B.

To the antenna wire provided is attached a sliding clamp to adapt the length of the wire to the spacing between available supports in the manner shown on the instructions attached to the cover. Clips, furnished with the wire, may be employed to secure the turned back or excess portions of the wire, effecting a shipshape arrangement in a short time.

14-3c. Description of Circuits—The tubes and circuit components are mounted on a rubber cushioned chassis arranged to absorb shocks. The tubes are clamped in place to prevent the possibility of accidental removal. A 6C5 tube is used in a tuned oscillator circuit, adjusted to 500 kc. A fixed vernier adjustment is provided to accurately tune the oscillator to the proper frequency.

The oscillator is capacitively coupled to the grid circuit of a 6L6 amplifier tube. This amplifier, in turn, is coupled to the antenna circuit through a network consisting of a plate coupling capacity and an antenna loading inductance. The antenna coil is tapped at frequent intervals to permit adapating the equipment to antennas of various dimensions. A variometer at one end of the antenna coil permits precise adjustment of the antenna circuit. The antenna coil tapping, controlled by the ANTENNA SELECTOR switch, and the variometer, operable by the ANTENNA TUNING control, are available from the front panel of the equipment. A neon lamp, coupled to the antenna circuit, indicates when the antenna is properly resonated.

14-3d. Power Supply—Power for this equipment is obtained from a 6-volt storage battery, which fits snugly into a compartment in the lower section of the case. This battery, removable from the front, is equipped with spill proof vents and will not leak if inadvertently turned on its side, although for operation it is intended that the battery be used in an upright position. The battery elements are contained in a monobloc, moulded case, sturdily constructed to withstand severe shocks.

Power from the battery is applied directly across the two tube heaters and the keying motor when the start button is pressed. This circuit remains complete throughout the operating cycle. During keying, a circuit is closed to the primary of a vibrator power supply, which applies high voltage direct current to the plates of the tubes. Modulation is accomplished by interrupting the 6-volt supply by means of a motor-driven commutator. The resultant pulsating d-c voltage is applied to the primary of a modulation transformer, the secondary of which is in series with the plate circuit of the amplifier tube. High level plate modulation which results in a signal of excellent readability is thus accomplished.

The power supply is adequate to provide in excess of 48 cycles of operation which may consist of hourly or half-hourly transmissions. It is also capable of operating continuously for one and one-half hours as required by the Federal Communications Commission.

14-3e. Keying Provisions—The keying motor drives a double reduction gear train and the modulation commutator. The first reduction gearing serves to rotate the keying cams which are cut to send the SOS signal. Either these cams, which operate at approximately 12 rpm, or the telegraph key, may be placed in the circuit by means of an associated switch.

A second gear train drives two cams which rotate once in 2½ minutes. One cam serves to keep the motor running and the tube heaters operated for a complete cycle once the START button is depressed. This cam also controls contacts which prevent keying until a delay period of approximately 30 seconds has elapsed to permit the tube heaters to attain operating temperature. A second cam on the slow gear train closes the keying circuit for one complete operation of the keying cams, thus sending a dash of approximately 4 seconds between each set of 3 revolutions of the keying cams.

The springs associated with the keying unit are arranged for instant breaking and the contacts are of the self-cleaning, wiping variety.

14-3f. Arrangement of Parts—The components, which are attached to the panel, are assembled in four units, each of which are separately removable for repair or replacement. The tubes and r-f circuit components are mounted on a chassis assembly, which is attached to the panel by rubber shock mounts. This assembly mounts above the battery compartment. The keyer motor, gear train, keying cams, timing cams and keying selector switch are mounted on a second chassis which attaches to the panel above the antenna parts compartment. The vibropack power supply unit is mounted on the panel at the left of the battery compartment. The loading inductance and associated variometer is placed above the vibropack, at the left of the battery compartment. The arrangement is such that the weight of components is balanced to promote portability and buoyancy.

14-3g. Normal Operating Procedure—The operating instructions are attached to the front of the equipment panel. Instructions for erecting the antenna are placed within the case cover. A code chart and procedure for transmitting both the international distress and auto alarm signals are included in these instructions. A circuit diagram, intended to be used for servicing the equipment, is cemented to the inside of the box.

The case is intended to be placed in an upright position where it is as protected from sea water and elements as conditions will permit. The cover is removed during operation, but may be replaced temporarily between transmissions, if this is felt necessary to protect the equipment.

To place the equipment in operation, the spool of copper ribbon, the end of which is attached to the ground lug, is removed from the parts compartment, the tie loop unfastened and the spool dropped overboard or attached to the ground stud on a metal lifeboat when such is supplied. The spool of ribbon will unwind, after being dropped overboard, providing a satisfactory ground connection. The depth of the end of the ribbon is of little consequence as long as the weight itself is under water. The depth must, however, be sufficient to insure that the weight is not lifted from the water when the boat rolls. The antenna should be installed in the manner prescribed, depending upon conditions and available supports. The spare wire should not be cut off, but folded back along the antenna and secured by the clamps provided for the purpose.

Having attached the antenna wire, the KEY SELECTOR switch is placed in KEY position. The START button is now pressed, starting the motor. Operating the hand key will perform no function until the tube heaters have attained operating temperature, which requires approximately 20 seconds. After that time has elapsed the key is pressed, and while being held operated, the ANTENNA SELECTOR switch is rotated until the neon bulb glows. The switch is left in this position and the ANTENNA TUNING knob rotated until the neon lamp glows most brightly. The KEYING SELECTOR switch is now placed on SOS position, or the KEYING SELECTOR switch may be left in KEY position and the hand key used for transmission of signals, if an operator is available. The equipment will transmit for 2 minutes, after which it turns itself off. It can be re-cycled again by pressing the START button.

CHAPTER 15

MARINE NAVIGATIONAL AIDS

Considerable progress has been made in recent years in the development of electronic devices for the purpose of aiding marine navigation. Among these electronic navigational tools are radio direction finders which have been in commercial service since 1921, as well as two newer developments, radar and loran. These devices, properly used, will prove of enormous value in providing information to assist in the navigation of vessels, particularly under conditions of poor visibility when the conventional celestial navigational devices cannot be used. This chapter deals with all three of these electronic aids to navigation, with particular emphasis on the operational aspects.

15-1. Radar—Radar, the development of which advanced at a tremendous rate during the war years, is one of navigation's newest and most useful aids. The operation of radar is based on the principle that transmitted radio energy is reflected by near-by and distant objects with the result that a small portion of the radiated energy is returned to the point of origin. The time required for the energy to return gives information permitting the distance of the reflecting object to be determined, while the direction from which the returning energy arrives provides information as to the direction of the object.

15-1a. Fundamental Principles of Radar—A radar system employs a transmitter which generates short pulses of radio-frequency power. These pulses are separated by spaces with a time duration considerably longer than the pulses. The radio-frequency pulses are channeled from the transmitter to a directional transmitting antenna by means of a suitable transmission line, coaxial cable, or wave guide.

The transmitting antenna, which is usually constructed in such a manner that it automatically "scans" the area to be investigated, radiates the short wave trains of radio-frequency energy in a sharp beam.

Reception of reflected radio-frequency energy (usually called "echoes") from surrounding objects (usually called "targets") takes place in the time intervals between the transmitted pulses. A sensitive receiver tuned to the same frequency as the associated transmitter is employed for the reception of these reflected signals. It is common practice to employ the same antenna for both transmission and reception although separate antennas may be used. With a common antenna, it is necessary to employ a fast-acting switching device to connect the antenna to the receiver during periods of reception and to protect the receiver from the strong pulse during the periods of transmission. Such a device is known as a "TR (transmit-receive) box."

The received echoes, after being suitably amplified, are displayed on an indicator, usually a cathode-ray tube. Since the range of detected objects is measured by the time interval elapsing between the transmission of a pulse and the reception of the echo, it is necessary to provide carefully designed timing circuits synchronized with the transmitted pulses.

Radar equipment operates in the very-high-frequency and microwave spectrum. One reason for the use of these frequencies is that a highly directional antenna is required and only at the very high frequencies is it possible to construct a highly directional antenna of reasonable proportions. Another reason for the use of very high frequencies is that the effective reflecting capability of a target increases as the wave length becomes small compared to the size of the object. The fact that very high frequencies are used in radar restricts the range to slightly beyond the horizon.

Early radar equipment made use of frequencies in the order of a few hundred megacycles, mainly because techniques for operating at higher frequencies had not yet been developed. Techniques and equipment permitting the use of much higher frequencies are now available and modern radar equipments operating at frequencies as high as 30,000 mc are in regular use.

As has already been mentioned, radar is accomplished by transmitting radio energy in brief pulses. The fact that the transmitting tubes are inactive and have an opportunity to cool during the spaces between pulses permits a high peak power output to be obtained without exceeding the plate dissipation rating of the tubes. This, coupled with the large power gains achieved in the highly directional transmitting antenna, makes possible tremendous effective peak power outputs (often expressed in megawatts) using relatively small transmitting tubes.

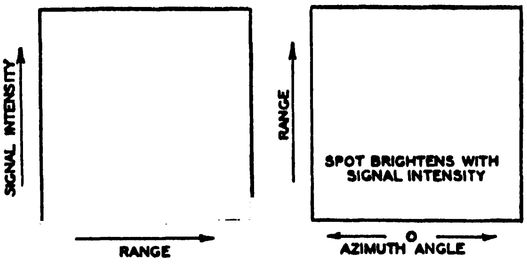
Inasmuch as radio waves travel at the speed of light (186,000 miles per second), a radio wave travels one mile in approximately 0.0000054 second and, as the same time is required for the return trip of reflected energy, approximating 0.0000108 second is required for radio energy to leave a transmitting antenna and return from a target one mile away. Because of the high speed of these events, it is necessary to express in microseconds the time intervals encountered in radar work. Therefore, using this unit of time measurement, the above values are 5.4 microseconds for a radio wave to travel one mile, and 10.8 microseconds for the energy to travel from the antenna to a target one mile away and back to the antenna.

15–1b. Pulse Duration—The time duration of a transmitted pulse is known as the pulse duration, pulse width, or pulse length. It is desirable that the duration of the pulse be very short, otherwise the transmitted pulse may be several miles in length making the detection of near-by objects impossible. As an example, let us assume that it is desired to detect an object one mile distant with a system employing a pulse duration of 20 microseconds. The time required for the forward edge of the transmitted pulse to travel one mile out and one mile back is 10.8 microseconds. Detection of objects at this distance would therefore not be possible, as the transmitter would still be in operation when the reflected energy from an object at this distance arrived. With a pulse duration of 20 microseconds, the minimum distance at which objects can be detected is approximately 1.8 miles. For this reason the pulse duration in modern radar sets is considerably less than the value discussed above, usually ranging from approximately 0.25 to 1.0 microseconds. Pulses of these short lengths permit the detection of objects at quite short distances. In some radar sets, the pulse duration is changed as a function of the actual maximum range setting in use, being lengthened when long range settings are employed and shortened when short range settings are in use.

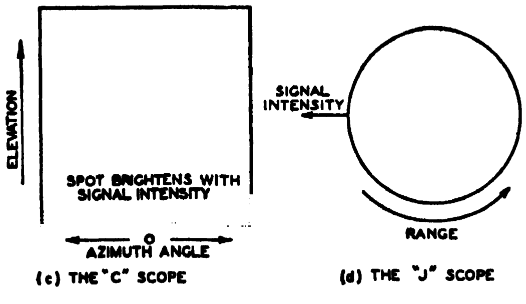
15–1c. Pulse Repetition Frequency—The number of pulses transmitted each second is known as the pulse repetition frequency (PRF) or the pulse rate. The pulse repetition frequency is a determining factor of the maximum range of the radar equipment. This may be explained in the following manner. When a pulse has been transmitted, the receiver picks up the returning "echoes" that are reflected from various objects. The time required for these echoes to return is a function of the distance of the object. Echoes from objects one mile distant require 10.8 microseconds, echoes from objects 5 miles distant require 54 microseconds, while echoes from objects 50 miles distant require 540 microseconds. From this it can be seen that at least 540 microseconds must elapse between the end of one pulse and the start of the following pulse to allow sufficient time for echoes to return from objects 50 miles distant. Therefore, the maximum number of pulses that can be transmitted each second is determined by the maximum range required. In many radar sets, the pulse repetition frequency is a function of the particular range setting in use, the rate being increased when short range settings are employed.

15–1d. Maximum Range—The pulse repetition frequency is not the only factor determining the maximum range of a radar set. Other factors involved are the frequency employed, the transmitter power, the gain of the antenna, the sensitivity of the receiver, and the effective "scattering" or reflecting properties of the target to be detected. In practice, the maximum range of the radar equipment in the detection of ships, as well as low flying aircraft, will be limited to slightly beyond the optical horizon of the radar antenna.

15–1e. Bandwidth Requirements—Owing to the fact that the pulses employed in radar systems are square-topped and of very short time duration, it is necessary that all r-f, i-f, and video circuits in the system pass a wide band in order to pass the pulses without seriously altering their wave shape. The need for wide-band circuits can be explained in the following manner. An analysis of a square-topped pulse shows it to be made up of a fundamental frequency and a large number of high order harmonic components. A limited frequency response at any part of the system would remove the high order harmonics, thereby destroying the square topped wave shape and furthermore, because of the relatively high time constants of a narrow band circuit, the pulse duration would actually be lengthened. To pass properly the pulses employed in current radar systems, bandwidths ranging from 2 to 10 mc are required.



(a) THE "A" SCOPE (b) THE "B" SCOPE



(c) THE "C" SCOPE (d) THE "J" SCOPE

Fig. 15–1. A few of the many types of radar indicator displays. The "J" scope (d) is similar to the "A" presentation but bends the range sweep around the periphery of the tube to obtain a longer sweep.

15–1f. Indicators—A great many systems of displaying the radar signals on a cathode-ray indicator tube have been devised. In each case, the object is to display the information in such a manner that it may readily be interpreted by the observer. Only the more commonly used indicator display systems are discussed here.

The "A" indicator (Figure 15–1a) presents signal intensity against a time base sweep which is calibrated in range. A photograph of an "A" scope presentation is shown in Chapter 16 in connection with the description of the U. S. Army moon radar experiment. The "B" indicator (Figure 15–1b) presents range on one axis against azimuth angle on the other axis. The intensity of this display is brightened as a function of echo intensity. The "C" indicator (Figure 15–1c) also employs intensity brightening with echo strength and presents azimuth angle against elevation.

The "J" indicator (Figure 15–1d) is similar to the "A" type, but bends the range sweep around the periphery of the cathode ray indicator tube to obtain a longer, and therefore more easily read, range trace. The PPI (plan position indicator) presents a map picture of the surrounding area by displaying azimuth angle and range in their actual relationship. Several photographs of PPI presentations are given later in this chapter.

15–1g. Shipboard Equipments—In this chapter we are concerned mainly with marine radar. Therefore, it has been decided to describe as completely as possible one of the shipboard radar equipments designed for use as a navigational aid on commercial ships. The set to be described is the RMCA model CR–101 shipboard radar and the material covering this equipment has been taken largely from instruction books, operating manuals, and other literature made available by the manufacturer of this equipment.

15–2. RMCA Model CR–101 Radar Equipment—Radiomarine model CR–101 radar is a design made especially for service on merchant vessels. It uses the 3.2-centimeter wave band which detects objects close to the water and which can be projected in a very narrow horizontal beam for good bearing resolution. A picture of the area around the ship is shown on a scope 12 inches in diameter. The radius of this area, from the center of the scope, is adjustable in four steps, giving ranges of 1½, 5, 15, and 50 miles.

Fixed and movable azimuth scales around the scope and a bearing cursor permit true or relative bearings to be measured. Range rings on the scope enable distances to be determined. In brief, the CR–101 radar will show the bearings and ranges of other ships, buoys, coastlines, and marked channels. This information, properly interpreted and used with judgment, can be a valuable aid in navigating the vessel under conditions of poor visibility.

15–2a. Design Considerations[1]—"In establishing the basic design of the CR–101, serious consideration was given to several important factors affecting the usefulness and reliability of a radar. These included choice of frequency; amount of transmitter power; need for short minimum range; simplified operating controls; fewest possible moving parts; and the minimum number of tubes.

"Choice of the proper frequency was of paramount importance. Both 3- and 10-centimeter radars had been in use during the war and information and techniques on both frequencies were available. However, the antenna beam width is directly proportional to the wave length for a given size of reflector; shorter wave lengths will, therefore, give better bearing resolution and sharper images. Furthermore, since at 3.2 centimeters an antenna which gives a 2-degree (or less) beam width already approaches practical limits in size for commercial use, it is apparent that the shorter wave length should be used. The antenna design of this radar provides a 1.6-degree horizontal beam.

"It was felt that the effects of sea return and heavy rain on 3-centimeter presentation had been overestimated and that the need for good bearing resolution had been correspondingly underestimated. While sea return is somewhat less on 10 centimeters due to the higher grazing angle of the first lobe over the surface of the sea, more important is the fact that buoys and other low targets are apt to be missed for the same reason.

"This has been borne out by extensive tests on the Great Lakes and Mississippi River. On the Lakes, where the trials included both 3- and 10-centimeter radars, the conclusion was reached that only the 3-centimeter designs could give the necessary performance. On the rivers, where the sharpest resolution is demanded at all times, the use of the higher frequency was a foregone conclusion. It is evident that radar for ocean-going vessels must likewise be capable of displaying the sharp outlines obtainable on 3 centimeters if it is to be of value in pilot waters.

"While 15 kilowatts was recommended as a suitable minimum peak power requirement, it was felt that ample reserve should be provided to meet all conditions of weather and propagation. Accordingly, a value of 30 kilowatts was chosen.

"Short minimum range and good range resolution were two major factors in the design to meet the needs of difficult piloting operations in narrow channels and harbors. Accordingly, a pulse length of ¼ microsecond was selected for use on the 1.5- and 5-mile range scales. Such a pulse has a length in space of 82 yards. Since the beam has to make a round trip for target detection, the theoretical minimum range would be 41 yards. However, to allow for receiver recovery time and spot size on the PPI tube, a value of 80 yards has been established for these factors.

"It may be shown that when the range scale in use is greater than about 5 miles, the minimum spot size of the cathode-ray tube becomes the limiting factor in determining image definition, rather than the ¼ microsecond transmitted pulse length. This makes it possible to use a longer pulse on the 15- and 50-mile range scales without sacrificing sharpness of the scope presentation. Accordingly, a one microsecond pulse is used on these ranges, thus enhancing the long range performance.

"By using a 3000-cycle repetition rate with the ¼-microsecond pulse, and a 750-cycle rate with the one-microsecond pulse, the duty cycle remains at 0.00075 and the average transmitted power is kept constant at about 23 watts.

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[1] Sections 15–2a through 15–2c reprinted from *RCA Review*, June 1947, Vol. VIII, No. 2. Frank E. Spaulding, Jr. "Radar for Merchant Marine Service."

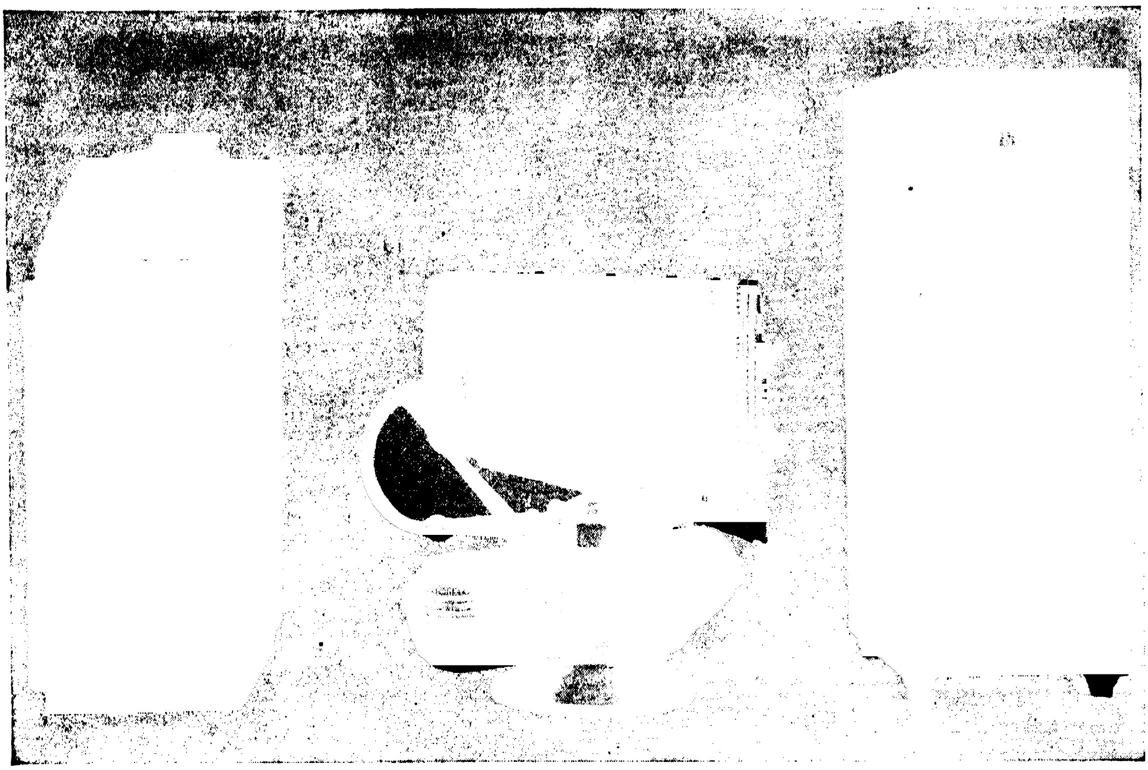


Fig. 15–2. The three basic units of the Radiomarine CR-101 radar. Left, indicator unit; center, antenna assembly; right, transmitter-receiver unit.

"With these repetition rates, the number of hits per beam width are 133 and 33 respectively. This insures that the echoes will build up to full brilliance on the scope even though the target may be small in size and may present a poor aspect to the radar beam.

"Particular stress is placed on keeping the number of operating controls at a minimum. This is felt to be particularly important since the equipment is operated by the ship's navigating personnel.

"It is also desirable to keep the number of moving parts at a minimum, both from the standpoint of reliability as well as quiet operation. Silence is essential in a pilot house when listening for fog signals. With this in mind, a stationary deflection-coil system for the PPI was chosen instead of the usual motor-driven rotating coil mechanism.

"The equipment consists of three major units, namely, the indicator, the transmitter-receiver, and the antenna assembly.

"1. *Indicator.* The indicator unit has been designed primarily for installation in the pilot house where it may be viewed and controlled by the navigating officers. It is built into a binnacle-type housing which contains the main operating controls and the 12-inch cathode-ray PPI scope. Its construction is illustrated in Figure 15–2 which shows the three major units of this equipment. This unit also houses a synchronizer chassis unit which generates all of the complex waveforms essential to operation of the radar, such as sweep, unblanking, trigger, range marks and sensitivity time control. The binnacle also provides room for the true-bearing assembly which, when connected to the ship's master gyro introduces north-stabilization of the PPI pattern and at the same time constitutes an extra ship's gyro-repeater station. The remaining space is devoted to high- and low-voltage power supplies associated with the synchronizer and scope. Operating controls for this

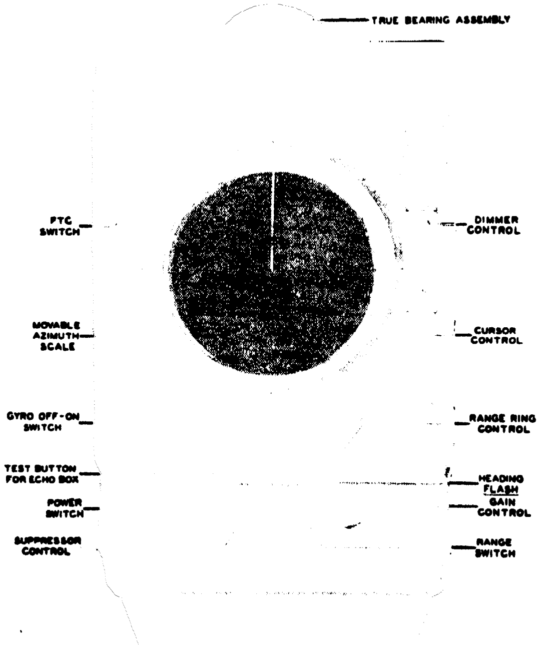


Fig. 15–3. Indicator control panel and 12-inch PPI scope.

equipment may be seen in Figure 15–3. This is a view of the top of the binnacle as it appears to the navigator. Most frequently used controls are: power, suppressor, range and gain. These four may be seen on the horizontal shelf at the front. Secondary controls are symmetrically arranged on the sloping panel and are also identified in Figure 15–3. Range indicator lamps show which range scale is in use and remind the user as to the distance between range rings.

"Behind a hinged lower door is an auxiliary test panel containing a built-in test meter, two-hour meter for observing 'stand-by' and 'operate' time of the radar, antenna motor-circuit breaker, 115-volt a-c convenience outlet and several fuses with individual blown-fuse indicator lamps. Several controls, normally set at the time of installation, also occupy this space. These are focus, intensity, video gain and manual tuning. An automatic-frequency-control off-on switch is also present.

"Certain mechanical features of the binnacle are of interest. The entire indicator mechanism rolls out of the housing for servicing. In this manner, all of the interior portions may be easily reached. The radar may be operated in this fully withdrawn position. The sloping operating panel housing the PPI tube is hinged and may be swung open and latched so as to give access to the azimuth scales and to the 12-inch tube itself. The true-bearing assembly cover is also hinged. This unit may be quickly reset whenever the ship's gyro has been shut down, as frequently occurs when the vessel is in port. The binnacle housing itself is of cast aluminum construction.

"2. *Transmitter-receiver Unit.* The transmitter-receiver unit may be located in the pilot house, chart room, or in any other location reasonably close to the antenna. The lower portion, behind a protective screen, houses the pulse modulator components, the magnetron and associated high-voltage power supplies. The receiver is located at the top of the cabinet while the receiver power supply mounts between the two. At the left side of the receiver is the radio-frequency mixer-duplexer unit. Behind this is mounted the 3.2-centimeter echo box. The receiver, its power supply and the echo box units, as well as the radio-frequency assembly, may be quickly removed and replaced if necessary during servicing operations.

"Access to the various units within this cabinet may be had by opening the hinged front door. This also exposes the transmitter test panel in the lower portion without permitting personnel to come in contact with dangerous high voltages. The test analyzer allows instantaneous checking of essential voltages and currents within the transmitter. It also contains a high-voltage circuit breaker, convenience outlet and fuses.

"On the lower left side is a small hinged door giving access to a replaceable filter cartridge associated with the blower unit which circulates air through the transmitter-receiver unit. The entire assembly is installed on shock mounts, and in addition, the receiver chassis is similarly protected from vibration.

"3. ***Antenna.*** The antenna assembly is installed on top of a tower or pedestal sufficiently elevated to allow 360-degree observation of the horizon without serious interference from obstructions such as smokestacks, king posts, and the like. An 8-inch diameter pipe structure with work platform and ladder has been found quite satisfactory for this purpose. Figure 15–4 shows a typical antenna installation utilizing a tower 35 feet high. The antenna is also shown in Figure 15–2.

"The 18 × 62-inch revolving grid reflector, shaped like a parabolic cylinder, establishes a horizontal beam pattern 1.6 degrees wide at the half-power points. The vertical pattern is 17 degrees wide to allow for rolling and pitching of the ship in rough weather.

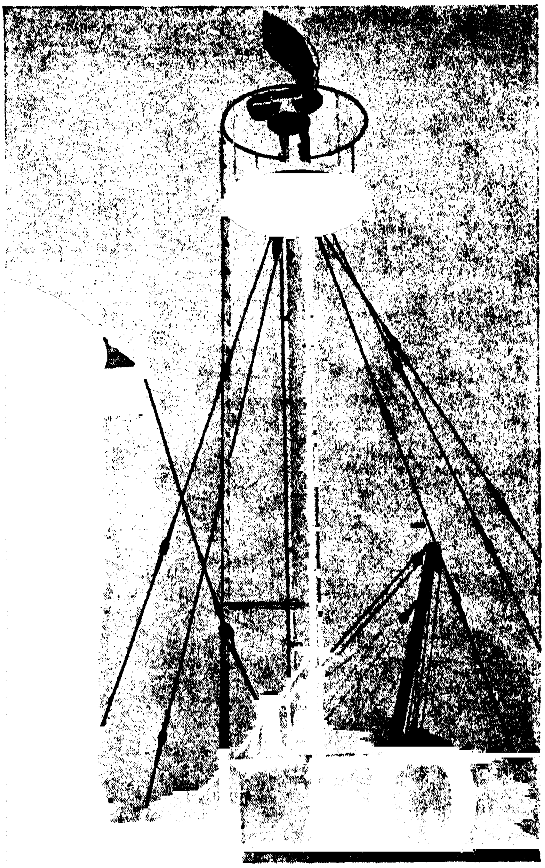


FIG. 15–4. A typical CR-101 antenna installation.

"Housed within the large end bell is the antenna-drive motor while the smaller end bell covers a synchro generator, heading flasher switch and terminal board. A phone jack and heading flasher adjustment are located behind a water-tight removable cap on the side of the smaller end bell. This allows installation and inspection personnel to plug in a standard telephone handset and converse with observers at binnacle or transmitter units while making necessary adjustments. A motor on-off switch is also present so that persons on the antenna platform may turn off the drive motor at will for reasons of safety.

"Reduction gearing to rotate the reflector and horn feed at approximately 10 revolutions per minute is contained within the oil-filled enclosure of the main casting. A rotating joint, also built into the aluminum casting, transfers the radio-frequency energy from the stationary wave-guide input to the revolving horn feed which 'illuminates' the reflector.

"A standard 115-volt watertight receptacle is included on the tower for servicing operations. Inter-connections between the antenna and other portions of the radar consists of the ⅝ × 1¼ inch waveguide, one coaxial cable, one 3 conductor and one 8 conductor armored shipboard cable. The wave guide is silver plated inside and out to insure low losses (0.026 decibel/foot). Connections between binnacle and transmitter units consist of three coaxial cables and two 8 conductor power and control cables.

"**15–2b. Circuits**—The basic system of operation may be observed by studying the block diagrams. The

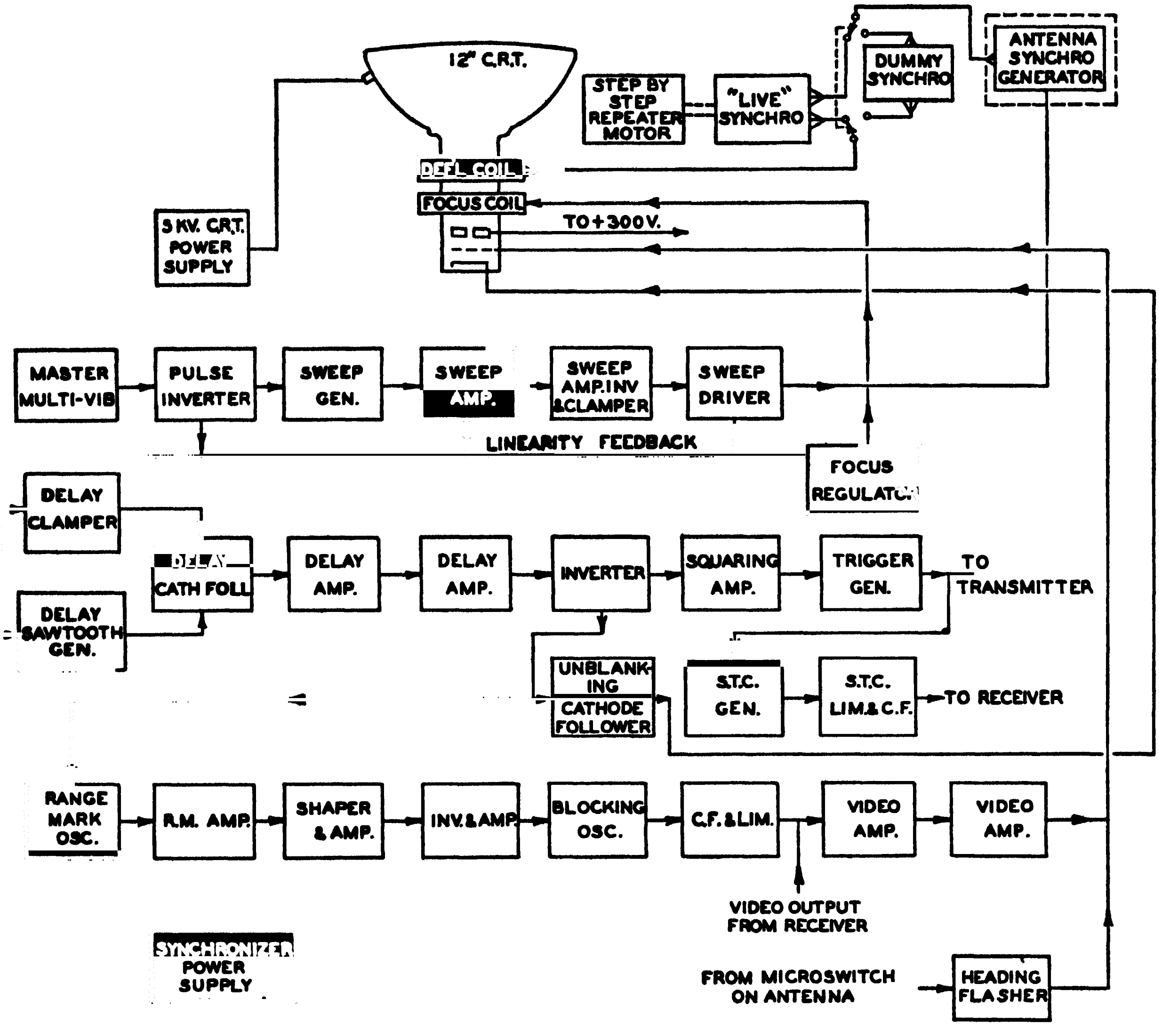


FIG. 15–5. Block diagram of indicator unit.

various circuit functions indicated on the diagrams are discussed as follows:

"(a) Generation of sweep, trigger, unblanking and range-marker waveforms in the synchronizer chassis (this establishes the basic timing sequence of the radar);

"(b) Passage of the sweep sawtooth waveform through the antenna synchronizer to modulate the sweep with the rotational azimuth information, return of the sweep waveform through the 'live' synchro-differential generator to take into account the ship's gyro data (for *True* presentation), or through the 'Dummy' differential generator (for relative presentation), and impression of the sweep voltages, thus modified, on the stationary three-phase deflection coil to appear finally as the revolving sweep line on the cathode-ray tube;

"(c) Transfer of the trigger to the transmitter and its subsequent amplification to a 12-kilovolt pulse applied to the magnetron;

"(d) 3.2-centimeter oscillation of the magnetron for the duration of the pulse, conduction of the microwave energy by waveguide to the antenna and its subsequent projection in a narrow revolving beam;

"(e) The gathering of the echoes by the antenna and their transfer to the receiver for amplification, detection and finally their application to the cathode-ray tube grid to produce the bright and dark areas of the picture;

"(f) Application of the unblanking pulse so that only the outward moving portion of the sweep will be brightened; and

"(g) Introduction of timing pulses as range rings to permit the measurement of distance on the PPI scope.

"1. *The Synchronizer.* An analysis of the synchronizer block diagram, Figure 15–5, in greater detail is given in the following paragraphs.

"The basic pulse repetition rate is established by a free-running master multivibrator. This square wave is used to excite a sawtooth sweep generator. Its output, when amplified and applied to a pair of 807 drivers is finally transformer-coupled to the coaxial line feeding the single-phase rotor of the antenna synchro-generator. The three-phase output of this generator ultimately reaches the deflection coil on the cathode-ray tube.

"Referring to the timing sequence diagram, Figure 15–6, it will be seen that with this deflection system, the cathode-ray tube beam inherently integrates the entire waveform. Thus, when line 'A' is at such a height above 'B' so that area I equals area II, then the cathode-ray tube beam will pass through the center of the PPI picture at 'A.'

"The function of the delay sweep generator now becomes apparent, since by delaying the firing of trigger, range markers and unblanking pulses until the point 'A' is reached, the sweep line will appear to start at the center of the tube. Echoes will then show up on the sweep between 'X' (the center) and 'Y' (the circumference) of the tube.

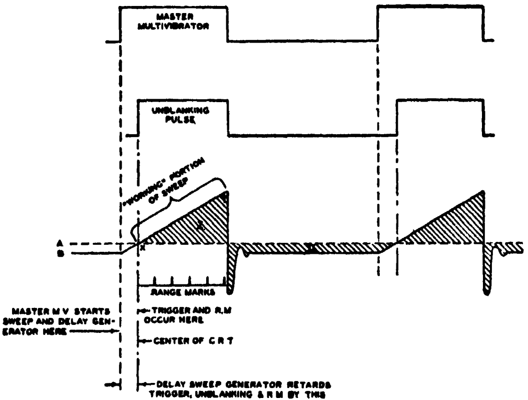

MASTER MULTIVIBRATOR
UNBLANKING PULSE
"WORKING" PORTION OF SWEEP
A
B
X
RANGE MARKS
MASTER M V STARTS SWEEP AND DELAY GENERATOR HERE
TRIGGER AND R.M OCCUR HERE
CENTER OF C R T
DELAY SWEEP GENERATOR RETARDS TRIGGER, UNBLANKING & R M BY THIS AMOUNT.

FIG. 15–6. Timing sequence diagram.

"The delay circuit consists of an auxiliary sawtooth generator which feeds a triode having an adjustable bias. Hence, the exact moment at which it starts to conduct may be controlled by its bias. After suitable squaring and amplifying, the unblanking pulse is obtained. Differentiation of the leading edge to fire a gas tube provides the sharp trigger pulse. Finally, the unblanking pulse excites the range mark generating circuits to produce the extremely sharp pulses required for clear range rings. The unblanking wave is applied to the cathode while range marks are combined with video from the receiver to reach the grid.

"2. *The Transmitter.* With reference to the transmitter block diagram, Figure 15–7, the low-level trigger pulse arrives from the synchronizer. A 'hard tube' pulser circuit is used containing a type 6SN7 tube as an isolation stage and low-level blocking oscillator, and then an 829–B tube as a high-level blocking oscillator. The pulse from the latter drives the 5D21 class-C amplifier or switch tube. A 12-kilovolt pulse appears across the plate-load resistor of this tube and thence is coupled to the magnetron cathode through a capacitor. The high power for this pulse is furnished by the 15-kilovolt power supply which incorporates two type 3B24 rectifier tubes in a voltage doubling circuit arrangement. Adequate protective devices for overload are incorporated, and layout of high-voltage components is in accordance with good transmitter design practice.

"The length of the pulse is established by the delay network in the 829-B grid circuit. The trigger pulse received from the synchronizer is about 40 volts in amplitude and approximately 1 microsecond long. This fires the 6SN7 low-level blocking oscillator to produce a sharper positive pulse of about 150 volts amplitude. It, in turn, is now applied to the 829–B and to the delay line simultaneously. The positive leading edge of this pulse fires the 829–B blocking oscillator which was previously quiescent. A pulse travels along the artificial delay line until it reaches the open end of the line and is then reflected back. This reflected pulse hastens the cutoff of the 829–B which then remains inoperative until the next positive pulse arrives. In this manner, the delay line determines the pulse length of the transmitted signal.

"The delay line has two sections. On the two shorter ranges (0–1½ and 0–5 miles) only the first portion is connected and a 0.25-microsecond pulse results. For the two longer ranges, a relay adds on another section, giving a 1.0-microsecond pulse.

"Experience has shown the hard tube modulator to be equal to or better than the hydrogen thyratron type for the relatively low power levels such as are used; in addition, it has greater flexibility for changing pulse lengths.

"3. *Radio-frequency Mixer-duplexer.* The magnetron mounts at the bottom of, and feeds power into, the duplexer waveguide, while the outgoing transmitter power is passed on the antenna waveguide protruding through the top of the transmitter-receiver cabinet.

"There are two horizontal branch chambers leading into the mixer portion of the assembly. The lower one has an aperture which passes a small amount of magnetron power to the automatic-frequency-control (AFC) crystal. The upper horizontal member contains the transmit-receive (TR) tube. This is the gas switching tube which short circuits the mixer input during the time the transmitted pulse is present. When the re-

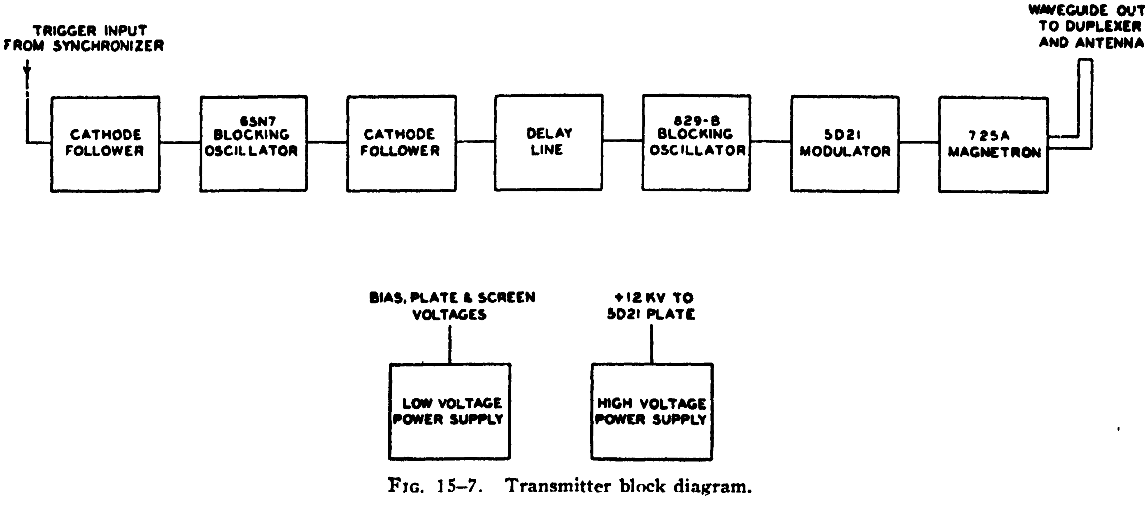

TRIGGER INPUT FROM SYNCHRONIZER
CATHODE FOLLOWER
6SN7 BLOCKING OSCILLATOR
CATHODE FOLLOWER
DELAY LINE
829-B BLOCKING OSCILLATOR
5D21 MODULATOR
725A MAGNETRON
WAVEGUIDE OUT TO DUPLEXER AND ANTENNA
BIAS, PLATE & SCREEN VOLTAGES
+12 KV TO 5D21 PLATE
LOW VOLTAGE POWER SUPPLY
HIGH VOLTAGE POWER SUPPLY

FIG. 15–7. Transmitter block diagram.

ceived echoes are present, this tube allows them to pass into the mixing chamber and signal crystal at the right.

"The 1B35 anti-TR tube may be seen in the duplexer portion. This tube prevents the weak echo power from being fed back into the magnetron and wasted.

"On the mixer portion at the right are the signal and AFC crystals and two shielded tube sockets. The lower one contains the 723A/B klystron oscillator which feeds its energy into both signal and AFC crystals. The upper socket is reserved for possible future beacon applications. Within this mixer assembly the signal, local oscillator, and magnetron voltages combine in the 1N23B crystals to produce the intermediate-frequency currents. The 30-megacycle signals from signal and AFC crystals pass to the receiver chassis through shielded coaxial cables.

"At the upper left is a 20 db directional coupler which is provided for system testing purposes and to which the echo box may be connected. The echo box, when installed, furnishes an artificial echo, thus providing a check on the over-all system performance when no targets are in sight.

"4. *The Receiver.* Referring to Figure 15–8, the receiver block diagram, it will be seen that this chassis receives the intermediate-frequency inputs from signal and AFC crystals. The weak signals are amplified through eight stages of 30-megacycle intermediate-frequency amplification and rectified. The resulting video pulses are further amplified, limited, and then passed through a coaxial cable to the indicator. After final amplification, they are fed to the cathode-ray grid.

"The AFC signal, after amplification, enters a discriminator network and d-c amplifier. By means of two sawtooth generators it controls the klystron reflector voltage in such a manner as to lock in the local oscillator to a frequency exactly 30 megacycles higher than the magnetron (and hence signal) frequency.

"The signal intermediate-frequency amplifier contains a low noise triode input stage, followed by three pairs of stagger-tuned stages using 6AK5 pentodes. The resulting gain is approximately 120 decibels with a band width of 6 megacycles. The over-all noise factor for mixer and receiver is less than 15 decibels above $KT\Delta F$ (the theoretical value).

"A fast time constant circuit (FTC) in the receiver is operated from the binnacle control panel. This assists in breaking up the solidarity of some types of interference such as sea return and heavy rain or snow.

"Sensitivity time control (STC) is very effective in minimizing response due to sea return. With this circuit arrangement an exponential waveform of adjustable amplitude and duration is produced. This is generated in the synchronizer and is applied to the receiver gain control lead. Its effect is to lower the gain of the receiver for targets close by and to increase the sensitivity to maximum for more distant objects. By suitable adjustment of the continuously variable suppressor control it is possible to thin out the solid pattern of sea return so that stronger ship targets, otherwise obscured, may be observed.

"The receiver contains a built-in test meter to provide quick checks on all essential voltages and currents. It is also possible to shift from AFC to manual tuning. Power to operate the receiver is supplied by the chassis immediately below the receiver.

"**15–2c. Performance Features**—The following tabulation lists the various performance characteristics of this radar equipment:

Frequency: 9320–9430 mc. Magnetron center frequency = 9375 mc (3.20 centimeters).

Transmitter peak power output: 30 kilowatts from type 725–A tube.

Range scales: 0–1½; 0–5; 0–15; 0–50 miles, with calibration in nautical or statute miles.

Range rings: 1½ mile range—3 rings—½ mile apart.
5 mile range—5 rings— 1 mile apart.
15 mile range—3 rings— 5 miles apart.
50 mile range—5 rings—10 miles apart.

Pulse length: ¼ microsecond on 1½ and 5 mile ranges.
1 microsecond on 15 and 50 mile ranges.

Pulse repetition rate: 3000 cps on 1½ and 5 mile range.
750 cps on 15 and 50 mile range.

Duty cycle: 0.00075 on all ranges.

Heading flash: This electronic marker shows ships heading (brightness of flash adjustable).

Range markers: ± 2 percent or 100 yards (whichever is greater).

Range resolution: Capable of showing two visible objects as two distinct images if they are separated by 80 yards in range with the radar operating on the shortest range scale.

Bearing resolution: Approximately 3 degrees or less.

Bearing accuracy: Less than 2 degrees error between antenna and indicator.

Display: PPI display on 12-inch cathode-ray tube.

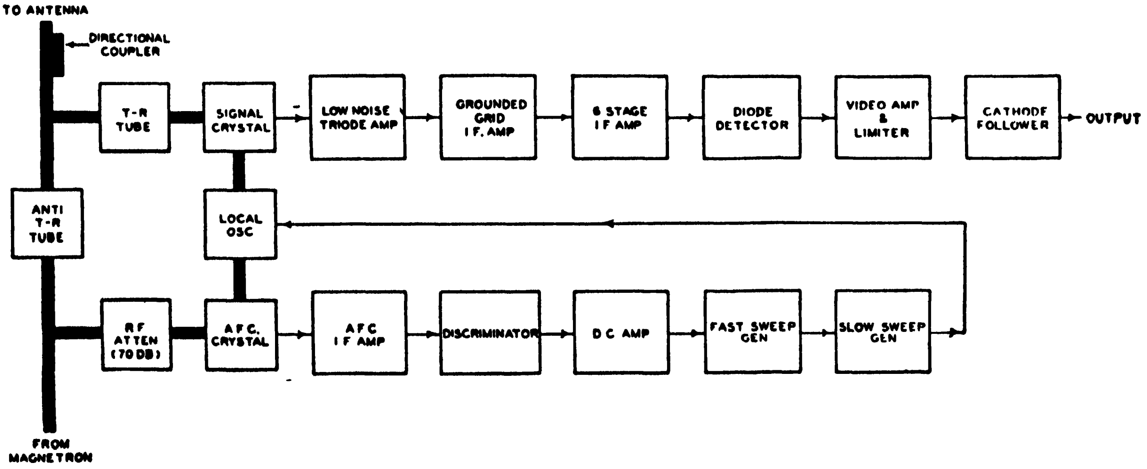


Fig. 15–8. Receiver block diagram.

Azimuth scales: Fixed illuminated scale—11½ inches in diameter—1 degree marks. Movable illuminated scale—10½ inches in diameter—1 degree marks.

Bearing cursor: Adjustable cursor line for measuring bearing of targets."

15–2d. Power Supply Requirements—An adequate source of power, free from wide or rapid swings in voltage or frequency, is essential for satisfactory radar operation. The individual responsible for the radar should check with engine room to insure that the following requirements are maintained:

1. *Ships with A-c Supply:* Line voltage 115 volts, 60 cycles, single-phase. Line current is 12 amp and power factor is 85 per cent. This is the load drawn by the radar. Line voltage variations should not exceed 5 volts either side of the normal 115 volts and frequency should be kept between 58 and 62 cycles.

2. *Ships with D-c Supply:* A special radar d-c to a-c motor generator (with starter) is furnished. This machine is supplied with either a 115- or 230-volt d-c motor to match the ship's d-c power supply. Current drain from ship's line is 20 amp at 115 volts or 10 amp at 230 volts. Engine room should maintain line within 5 volts (at 115) or 10 volts (at 230).

15–2e. The Indicator Unit—Maximum utility and performance from CR–101 radar equipment requires a clear understanding of the various controls on the indicator unit. Since the indicator unit is that part of the equipment which will be used regularly by the navigator, a detailed description of the controls and their functions is given below.

1. *PPI Scope.* The 12-inch diameter cathode-ray tube, commonly referred to as the PPI (plan position indicator) or scope, is mounted in the top section of the indicator unit at an angle of 30°. The face of this tube is waist high and it may be viewed with convenience when standing in front, or at either side, of the indicator. Two detachable "viewing hoods" for shielding the scope are furnished. Objects picked up by the radar beam are frequently referred to as "targets," which may be other vessels, buoys, shore lines, etc. Therefore, in this book the word "targets" will be used to denote such objects. When the radar is in operation, the targets appear on the PPI in polar coordinates.

2. *True Bearing Assembly.* Vessels which have a gyrocompass system may have their CR–101 radar tied in with the gyro by means of a True Bearing Assembly (TBA). This assembly, which is an accessory, is mounted in the upper section of the radar indicator. Indicators so fitted may be identified by the drum type repeater scale which projects at the top of the unit. The purpose of the True Bearing Assembly is automatically to stabilize the PPI picture so that north is "up" on the scope. The use of the TBA is discussed below in connection with the fixed and movable azimuth scales, gyro off-on switch, heading flash, etc.

3. *Fixed Azimuth Scale.* Around the outer edge of the PPI scope, there is mounted a fixed azimuth scale 11½ inches in diameter, calibrated in one degree divisions. This scale is *red* to distinguish it from the inner, or movable, white azimuth scale.

When a True Bearing Assembly is installed in the indicator, the *fixed* azimuth scale is used to determine bearings with respect to true north. This is known as the gyro "on" condition. If the indicator does not include a TBA (or with gyro switch in "off" position), then the fixed azimuth scale is used to determine bearings *relative to the ship's bow.*

4. *Movable Azimuth Scale.* The movable azimuth scale, white, is 10½ inches in diameter and may be rotated by the left hand knob. There are two uses for this movable scale and they are the reverse to that of the fixed scale. Assume the TBA is in use (gyro on). North will be "up" or at zero on the fixed scale. Now the movable scale should be turned so that *its* zero lines up with the heading flash. Then the bearings of targets read against the movable scale are relative to the bow.

Next assume there is no TBA or that the gyro switch is off. We wish to take true bearings on targets. The fixed scale now shows targets relative to the bow. Determine the ship's true course (from corrected compass course or other methods). Say the course is 60. Turn the movable scale until 60 on that scale lines up with zero on the fixed scale. Now the bearings of targets read against the movable scale are true. To summarize the use of either scale, refer to the following tabulation:

WITH "GYRO OFF"

(*or no True Bearing Assembly installed*)

Fixed Scale: Targets are relative to bow.

Movable Scale: Targets are relative to north by setting ship's true course on movable scale to coincide with zero on fixed scale.

Heading Flash: Will coincide with zero on fixed scale.

WITH "GYRO ON"

(*True Bearing Assembly installed*)

Fixed Scale: Targets are relative to true north.

Movable Scale: Targets are relative to bow by setting zero on movable scale to coincide with heading flash.

Heading Flash: Will indicate ship's true course on fixed scale.

5. *Gyro Off-On Switch.* The GYRO OFF-ON SWITCH, to the left of the PPI, is used to control the presentation of the picture. This switch functions only on indicators which have a TBA installed. With the gyro switch turned on, the zero on the fixed azimuth scale represents true north. If the

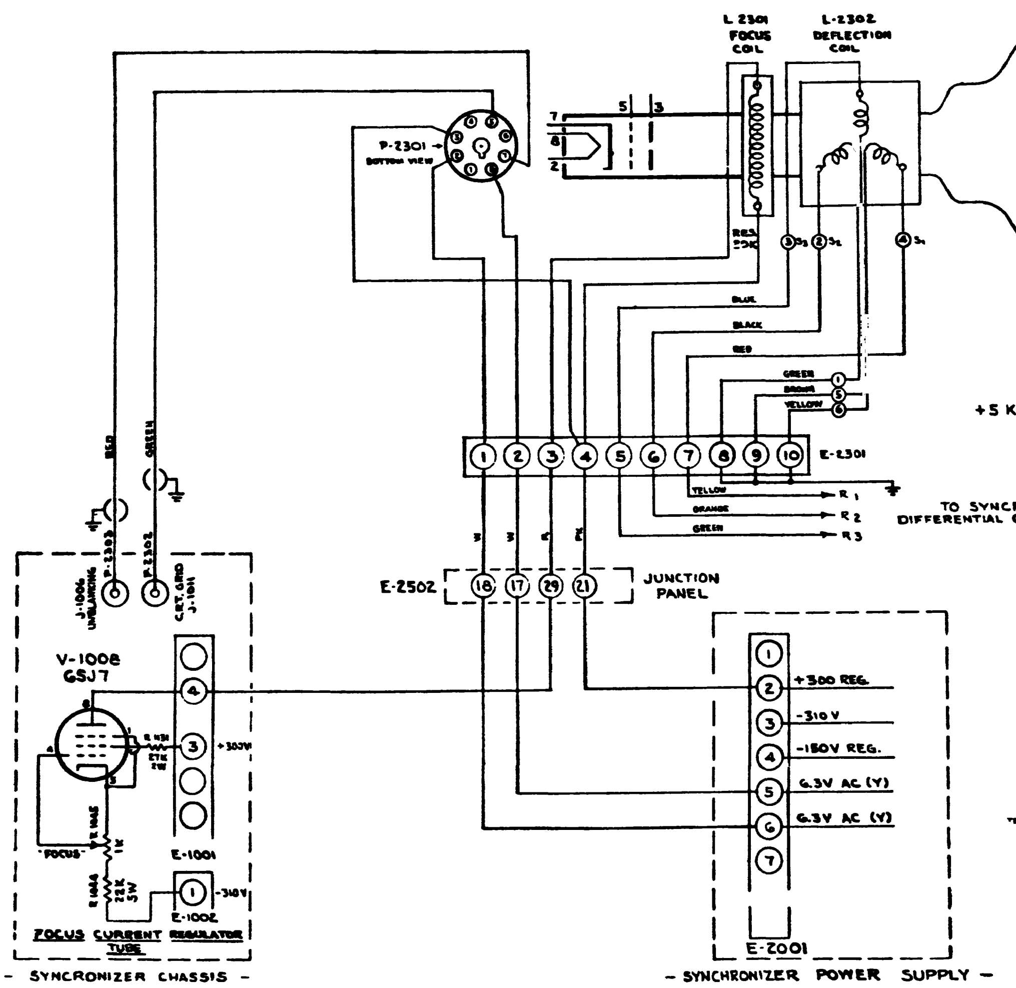


Fig. 15–9. Wiring of cathode-ray tube circuit.

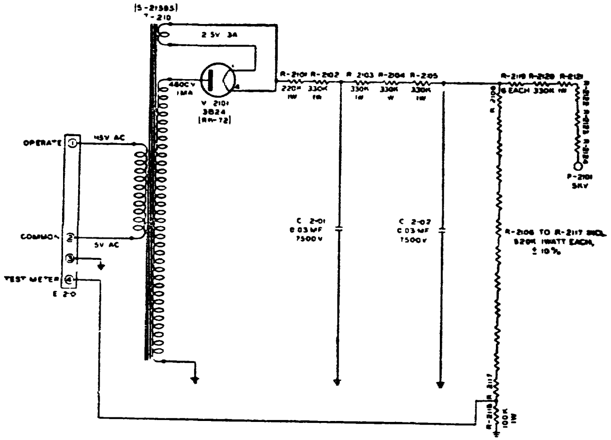


Fig. 15–10. Schematic diagram 5000-volt cathode-ray power supply.

vessel makes a turn, or yaws in a heavy sea, the picture remains stationary, thereby making it unnecessary for the targets to reestablish themselves on the PPI.

The "gyro on" condition is well adapted for comparing the PPI picture with sailing charts, as in both cases north is "up." On the other hand, when piloting in restricted waters, proceeding along a channel while picking up buoys or other markers on the radar, the "gyro off" condition may be preferred. In this case, the ship's heading flash appears at zero on the fixed azimuth scale and the bearing of targets on the PPI is relative to the ship's bow. It is easy to determine which method of presentation is being used because the heading flash in the "gyro on" condition will not be at zero on the fixed scale unless the vessel's course happens to be true north at that time.

When a TBA is installed in the indicator, it includes an illuminated repeater azimuth scale. This scale is equivalent to an ordinary gyro repeater, and it will show the ship's true course at all times. This action of the repeater scale is independent of the radar power or the GYRO OFF-ON SWITCH, and therefore may be used whether or not the radar is in operation. An adjusting knob and cut off switch are provided under the repeater scale housing for the purpose of setting the repeater in the event that the ship's master gyrocompass has been shut down for any reason.

6. *Cursor Control.* A knob at the right of the PPI is used to rotate a bearing cursor. This cursor line appears across the face of the PPI and may be adjusted so that it intersects any targets of interest. The bearing of the target is then read from the outer or inner azimuth scales, as described earlier.

7. *Heading Flash.* The heading flash is simply a bright radial line on the scope to show when the antenna is pointing dead ahead. This flash occurs once every six seconds. As explained previously, the heading flash will coincide with zero on the fixed scale with gyro off, or it will indicate ship's course with gyro on. The flash may be dimmed or brightened by using the small knob marked HDG FLASH located between the RANGE and GAIN controls.

There are two important uses for the heading flash. On relative bearing (gyro off) the flash marks off on the scope a line dead ahead. When passing through a group of channel buoys the course may be set to keep the buoys on either side of the flash. Other similar uses will be apparent. On true bearing (gyro on) the flash will appear on the fixed scale to show the ship's heading. Example, the ship is heading due south. Flash shows at 180° on fixed scale. This action may seem confusing until one remembers that the flash is a constant reminder of the time and angle (zero with respect to bow) when the radar "looks" dead ahead.

Continued accuracy of the heading flash is essential. This may be checked in clear weather by visual observation of dead ahead targets and comparing with the scope. Apply the necessary correction if error is constant or have the flash reset. When looking at dead ahead targets that may be obscured by the flash, use the control to temporarily dim or extinguish the flash.

8. *Dimmer Control.* The dimmer control is a small rheostat to the right of the PPI and may be used to adjust the illumination of the fixed and movable azimuth scales. Ordinarily, this control will be used to brighten the scales when taking bearings and then turned to the left to dim the light so as not to interferee with the targets on the PPI.

9. *Range Ring Control.* Range rings in a radar system are used to determine the distance between the ship and any targets which show on the PPI. These range rings are produced electrically and consist of a group of luminous concentric circles on the face of the tube. The range ring control, to the right of the PPI, allows the rings to be brightened or dimmed. The latter condition is desirable when a range ring tends to obscure a target which falls exactly on one of the rings. For convenience in identifying the number of range rings and their spacing in miles, there is located directly beneath the PPI a nameplate which shows the number of range rings for each of the four ranges as follows:

Range (miles)	*Range Rings*
1.5	3 Rings ½ mile apart
5.0	5 Rings 1 mile apart
15.0	3 Rings 5 miles apart
50.0	5 Rings 10 miles apart

For high seas service, range rings are calibrated in nautical miles (6080 feet). For use on the Great Lakes, or inland waterways, range rings are calibrated in statute miles (5280 feet).

10. *Power Switch.* A three-position power switch, controlled by a large knob, is mounted on a horizontal shelf in the upper left section of the indicator. The positions of the switch are OFF, STANDBY, OPERATE. When in the OFF position, the entire radar equipment is shut down. In the "STANDBY" position, the various radar tubes are kept heated and a small rectifier in the transmitter is turned on. In the OPERATE position, power is applied to place the complete radar system in operation.

In order to allow sufficient time for certain tubes to heat up, the radar uses a three-minute time delay relay. In other words, if the switch is placed from the OFF to the OPERATE position, a time interval of three minutes must elapse before the system goes on the air. For this reason the "standby" position is provided and the switch may be placed in this position a short time before it is desired to use the radar.

The power switch should always be turned from OPERATE to STANDBY if the radar is to be left unattended for short periods. This avoids excessive wear and tear on expensive tubes and other parts.

11. *Suppressor Control.* The suppressor control appears at the right of the power switch. The purpose of this control is to minimize obscuring of targets near the ship during a heavy sea. The waves of the sea can also act as targets and appear on the PPI as a fairly bright pattern of light. The effect is variously known as "sea return," "sea echo," or "clutter." Under conditions of moderate or heavy sea return, small targets may be obscured and the suppressor knob and gain control should be adjusted while watching the PPI so as to secure the greatest possible contrast between the sea and any targets.

The suppressor control provides a continuous adjustment so that optimum results may be had under various circumstances. In addition to the use of the suppressor for reducing sea return, it may be employed to clarify the center of the scope when there are strong nearby targets. For example, when navigating in harbors and narrow channels, the suppressor control, as well as the gain control, should be carefully adjusted when looking at targets within a few hundred yards of the vessel.

12. *FTC Switch.* The FTC switch (fast time constant) is marked OFF—RAIN-SNOW. Use in the RAIN-SNOW position during very heavy rainfall or snowfall to increase the target contrast. This switch should normally be OFF under other weather conditions.

13. *Range Switch.* The range switch is a four-position control and is used to select the desired range scale. The ranges are 1½, 5, 15 and 50 miles. When the range switch is placed in any one of its four positions, it causes one of the four range indicator lights to be illuminated beneath the PPI. This arrangement gives a positive indication of the range in use, even when operating in a darkened wheelhouse. Recommendations for use of the range switch are covered under "Operating Procedure."

14. *Gain Control.* The gain control on the indicator is roughly equivalent to the volume control on an ordinary radio. When this control is turned to the right, it adjusts the brilliance of the targets on the PPI and, to a considerable extent, it determines the range over which targets will be picked up.

A few hours' practice in using the gain control will enable the navigator to secure the best contrast and definition of targets. For exploring the immediate vicinity of the ship, the gain control is adjusted to a fairly low value. This sharpens strong targets near the center of the PPI. As the gain control is advanced, targets near the center tend to merge, while others at greater distances will stand out very clearly. While observing such distant targets the gain should be advanced to the point where receiver noise just begins to appear on the scope as a light or mottled background.

15. *Hour Meters.* Two hour-recording meters, one showing "standby" time and the other "operate" time, are located behind the lower door of the indicator. These meters are used to keep a log on the use of the radar. The left hand meter records *combined* standby and operate time in hours. The right hand meter records operate time *only*. Therefore, the left meter will normally read somewhat higher because combined standby and operate time will exceed straight operate time. Too great a difference in the reading of the meters indicates excessive or unnecessary standby operation.

16. *Test Button and Echo Box.* All indicators are fitted with a button marked TEST which is located between the power and suppressor controls. This button is for use in connection with an echo box when the latter is installed in the transmitter-receiver unit as an optional accessory. With such installations the echo box may be used as an artificial target to test the radar as follows.

Place the range switch at 1.5 miles. Make sure the suppressor control is at zero. Hold down the test button and advance the gain control while watching the scope. This will cause a series of radial lines, like spokes on a wheel, to appear from the center of the scope outward to some point between the 0.5 and 1.0 range rings. If the spokes are shorter in length than those normally observed, or if no spokes at all appear, this is an indication of lowered performance and the radar should be used with caution and serviced as soon as possible.

After testing with the echo box, be sure that the center of the scope is "clear." After using the echo box, with the test button, it may occasionally stop in a tuned position which will cause the center of the scope to be filled with a bright area, thereby obscuring natural targets. To correct, press the test button a few times until the center of the scope is clear. In general, when using the echo box the surrounding area must be free from numerous natural targets, or sea return, in order to distinguish the echo box spokes. Whether or not the radar is fitted with an echo box, daily experience with real targets is a good guide in determining whether or not the range and general performance are normal.

15–2f. Operating Procedure—Before placing the radar in operation, the navigator should be familiar with the various controls on the indicator unit as previously outlined. If the indicator includes a True Bearing Assembly, steps should be taken to insure that the repeater azimuth scale has been adjusted to coincide with the ship's course. This is done by opening the hinged cover over the repeater scale, placing the switch in the OFF position to remove power from the repeater motor, and then adjusting the scale, with the knob provided, to the ship's course. The switch should then be placed in the ON position and the cover fastened in place.

1. *Placing the Radar in Operation*

(a) Turn POWER SWITCH to the OPERATE position. Three minutes must elapse to allow the time delay relay to function. If desired, the power switch

one showing “standby” time and the other “operate” relay to function If desired, the power switch

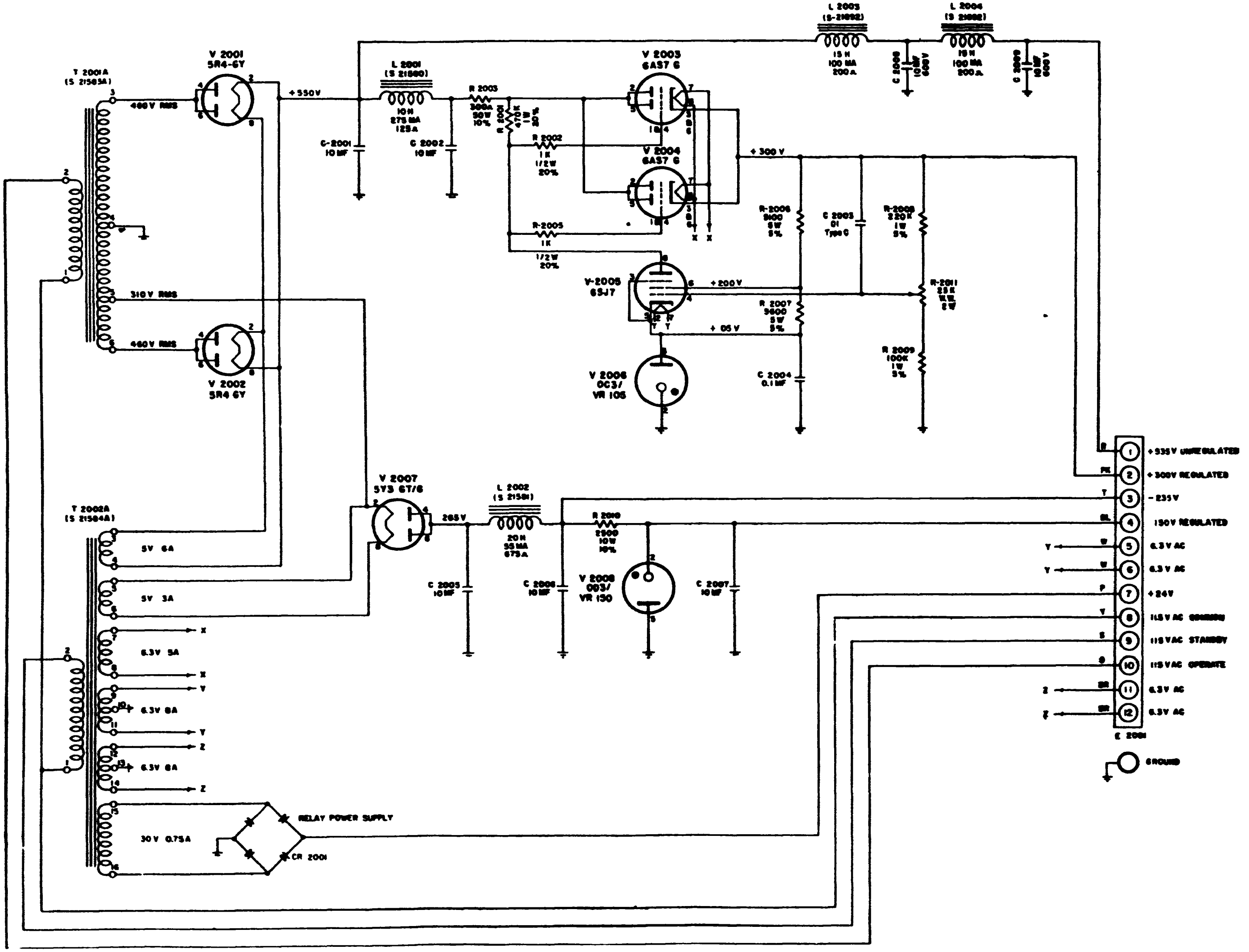


FIG 15–12 Wiring of synchronizer power supply

may be placed in the STANDBY position several minutes before the radar is to be used. The POWER ON light will indicate at the end of this three minute interval if switch is on OPERATE.

(b) Make sure the SUPPRESSOR control is set at zero.

(c) Set RANGE SWITCH to the desired range; 1.5 5, 15 or 50 miles. The two lower ranges are best when navigating in channels, or restricted waters, while the two higher ranges are desirable when on the high seas.

(d) Adjust the gain control by turning to the right until targets appear on the scope. Advance this control until the best contrast is observed between the targets and the general background.

(e) If excessive sea return or local rain squall interference is observed on the scope, adjust the SUPPRESSOR control by turning to the right until the picture is clearer. This should be done with care so that the area near the vessel appears mottled or flaky. Too little SUPPRESSOR allows sea return to brighten unduly the scope. Too much control will darken center of scope and may wipe out targets.

(f) Use the GYRO OFF-ON SWITCH as required, remembering that with GYRO OFF, zero on the fixed (red) scale represents the bow, whereas with GYRO ON the zero on this same scale represents true north.

(g) The movable AZIMUTH scale may be adjusted to show targets relative to north, or relative to bow, as previously explained.

(h) Use CURSOR control to determine bearings of targets.

(i) Use the FTC SWITCH in the RAIN-SNOW position when conditions warrant.

(j) Adjust RANGE RING control to brighten or dim range rings.

(k) Adjust HEADING FLASH control to brighten or dim flash, as desired.

(l) For daytime use, or in a bright wheelhouse, use one of the viewing hoods over the PPI scope. The short hood over the scope is useful at night to keep the glow from the helmsman's eyes.

2. *Overload Relay Protection.* The radar transmitter uses certain relays to protect the magnetron from overload. When these relays "kick out," the red light behind the lower section of the transmitter door will be extinguished. When this occurs, turn the indicator power switch to the STANDBY position for 10 seconds. Then place switch in OPERATE position which will close overload relays and restore normal operation.

15–2g. Interpretation of Scope Pictures—The mariner who has studied the preceding sections will understand the use and function of the various controls on the indicator. From this point on he will be concerned with the interpretation of the PPI scope pictures and the manner in which they can best be used to aid in the navigation of the vessel. The radar can "see" targets in thick weather that are invisible to the naked eye. On the other hand, the eye, in clear weather is a better direct judge of size, profile, or speed. It follows, therefore, that skill in reading the scope is a matter of experience plus a knowledge of the advantages and limitations of radar.

Use of the radar in clear weather is recommended to acquire experience. Targets can be viewed directly with the eye, or through binoculars, and then compared with their appearance on the scope. One of the viewing hoods may be placed over the scope to exclude outside light. After observing targets on the scope they may also be compared with the chart in areas where coastlines, buoys, lightships, etc., may be picked up. Practice along these lines, in clear weather, will be of great value later, when the radar is used during fog or darkness, because the navigator will then be familiar with the characteristics of the scope picture.

It is well to bear in mind that there are four main uses for the radar. While these uses overlap in practical navigation, they may be summarized as follows:

(a) Anti-collision, on the open sea, such as observing the course and position of an approaching vessel.

(b) Piloting, such as entering a harbor, or when in a river, with buoys or other markers showing on the scope.

(c) Position finding, where the radar is used to determine the bearing and range of targets which can be identified on the scope and on charts.

(d) Storm warning, in cases where heavy rain squalls may be noted on the scope and their distance and movement plotted.

Several typical examples of how the radar may be used are given below. A simple case is described first, followed by other instances of a more involved nature. Remember that the use of radar does not alter the Rules of the Road, or the relations between the privileged and burdened vessel. An approaching vessel may or may not have a radar, and each ship has a responsibility not to take action which might confuse the other.

Example No. 1. Vessel is in the open sea, proceeding at normal speed. Range switch is at 15 miles. Gyro switch is off, for relative bearing. The heading flash appears at zero on the fixed scale. Gain control has been adjusted to a medium high value. Three range rings show on the scope, each 5 miles apart.

A target is observed off the port bow about midway between the center and outer range ring. This shows the range to be about 12.5 miles. The bearing cursor is placed over target and reads say 340 on the fixed scale. The target is, therefore, 20° on the port bow. If desired, the movable scale can be placed with its zero under the cursor and it will then read 20 against the zero on the fixed scale.

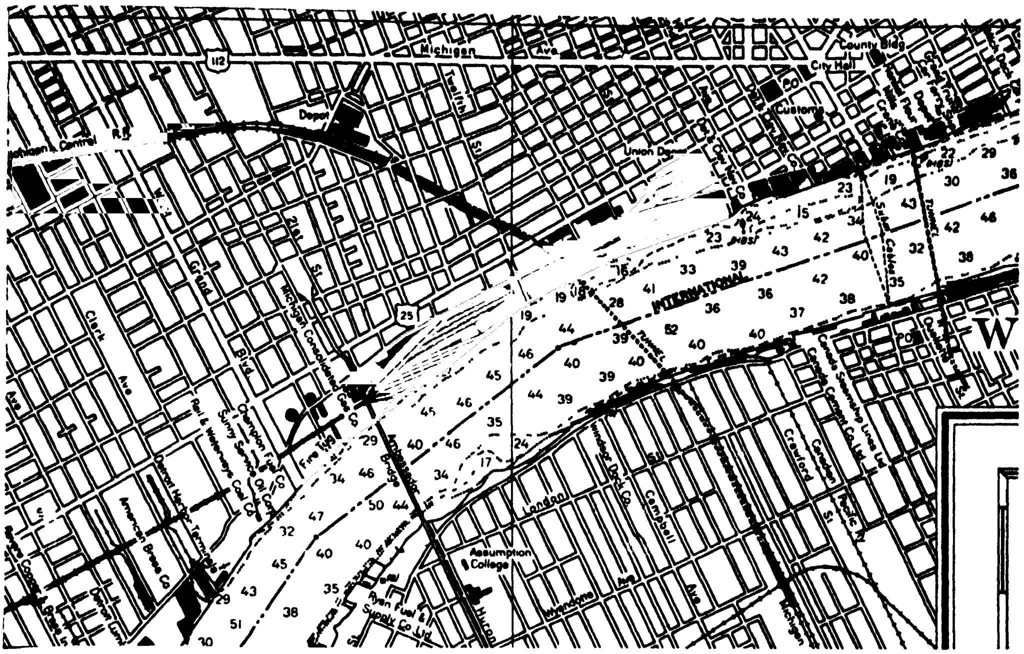


Fig. 15–13 Chart of Detroit River area.

The target is now watched, and bearing and range checked. If the target moves down (toward center of scope) and stays under the cursor, this indicates a collision course. When the target comes inside the first range ring (5 miles), change the range switch to the 5 mile position. This will move the target out near the edge of the scope and permit more accurate bearings to be measured with the cursor. Wait 15 or 20 seconds, for the old picture to fade out, then readjust the gain control. Make frequent observations of bearings and range. If the target is moving (such as an approaching ship), this will be disclosed by two or more plottings, making due allowance for the movement of your own vessel during the intervals.

Finally, if the target is getting close to the 1 mile ring on the 5 mile scale, switch to the 1.5 mile range. Unless the sea is calm, there may be observed sea return which tends to obscure targets near your vessel. Adjust the suppressor and gain controls to make the target stand out as clearly as possible. On the 1.5 mile range special care must be taken to allow for the relatively fast movement between your own and a near-by vessel. Two approaching ships, each making 10 knots, will in 1½ minutes reduce the distance between them by about 3000 feet. This is the spacing between each range ring on the 1½ (nautical) mile scale. (Spacing

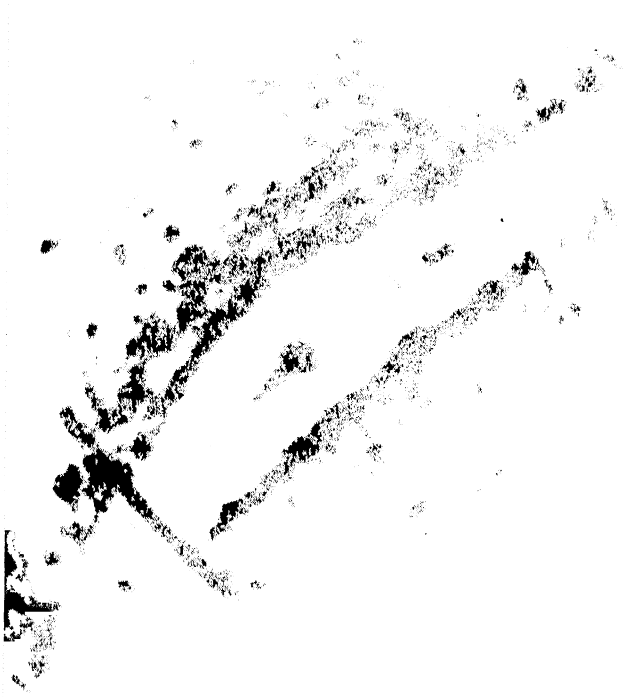


Fig. 15–14. PPI of Detroit River area, 1½ mile range. Compare with Figure 15–13.

is 2640 feet on radars with 1½ statute mile scale.)

Example No. 2. Vessel is entering a harbor or channel. At the start, the 5-mile range will probably be used. Gyro switch will be off and heading flash will be "up" for relative bearings. The navigator will endeavor to recognize, on the scope, known lightships, buoys, or prominent land projections. Gain and suppressor should be adjusted for best target brightness, taking care not to "black out" targets within a few hundred yards of the ship.

As the vessel nears a group of buoys marking the channel, change range to 1.5 miles. Heading flash is watched and the course altered as necessary so that flash intersects "pairs" of buoys or falls on a buoy up ahead that is being used as a ranging marker. Presence of other ships in the channel and their course and speed is watched on the scope. Buoys which have been passed may be watched on the "bottom" section of the scope.

With short range operation, 1.5 miles, and as targets appear within the first range ring, 0.5 mile, remember that the distance as shown on the scope is measured from the antenna position on your ship. On some vessels the bow may be 75 yards or more ahead of the antenna, and this distance should be taken into account when viewing forward targets a few hundred yards away.

Example No. 3. Vessel is within radar range of lightships, prominent land projections or other objects whose position is shown on charts. The navigator wishes to obtain a fix to determine his position. Range switch is adjusted to put the target out near the edge of the scope, for best bearing accuracy. Gyro switch is "on" to put north at top of scope, for indicators using a true bearing assembly. As an alternative (with no TBA or gyro switch off), the movable azimuth scale may be set to the ship's true course, against zero on fixed scale.

Assume a lightship is picked up on the scope and appears about 11 miles distant. On the 15 mile range this will be just outside the second, or 10 mile range ring. Watch the target and just as it passes under the 10 mile range ring use cursor to take a true bearing. This gives a one point fix, since range and bearing are known and the position can be plotted on the chart. Remember that true bearing is shown against the fixed scale with gyro on and TBA in use, or against the movable scale with gyro off when movable scale is set as described above.

As a check on the one point fix, cross bearings and ranges may be taken on two or more targets that can be identified on the scope. This is useful because the several bearings will intersect to show the ship's position. As a further check, the distance can be estimated fairly closely if the targets fall between range rings, or with considerable accuracy with targets right on a ring.

Lightships or other charted targets that stand out clearly on the scope give the best bearings and ranges. It will be apparent that land masses, shore profiles and the like are less accurate as targets because of their variable size and shape.

Example No. 4. Many navigators use their radar to detect approaching rain squalls. In areas where very heavy rainfall may be encountered, it may show up on the scope as a bright mass. Moderate or light rainfall is not so apparent. If a squall is detected early, usually on the 15 or 50 mile range, its general area and movement may be watched and an estimate made whether the ship will pass through the storm path. Meanwhile the location of other ships in the vicinity should be noted so that appropriate action may be taken if visibility becomes poor.

With your vessel in the storm area and very heavy rain or wet snow falling, radar visibility (on the scope) may be impaired. Make the best use of the suppressor control and the FTC (rain-snow) switch when watching targets under such conditions. While complete radar "blackouts" are rare, they can be easily recognized and due caution should be exercised. In some instances the radar will "see" through a heavy local storm area, picking up targets outside that area, but with targets obscured in the immediate vicinity.

Example No. 5. Action of true bearing assembly (TBA): When the gyro switch is "on" this connects the TBA electrically to the PPI scope so that north is at zero on the fixed scale. The heading flash then shows ship's course when read against the *fixed* scale. This action may seem confusing at first since the navigator is accustomed to viewing targets relative to the bow. The advantage of the gyro "on" condition, aside from giving true bearings, is that the picture is "stabilized." When the vessel makes a turn or rolls, pitches and yaws, the picture remains steady. If bearings are being taken under these conditions, the targets do not move around on the scope and have less tendency to "smear." In the opposite case, with gyro switch "off," should the vessel make a 30 degree right turn, it will be necessary to wait a short time until the targets move left to reestablish themselves 30 degrees from their former position.

Assume ship's true course is 180. With gyro switch "off" heading flash appears at zero on fixed scale. Now with gyro switch "on" heading flash shows at 180 and the entire picture is turned upside down. However, by remembering that the flash always shows heading, the bearing of targets relative to the bow may be noted either side of the flash. If desired, zero on the movable scale may

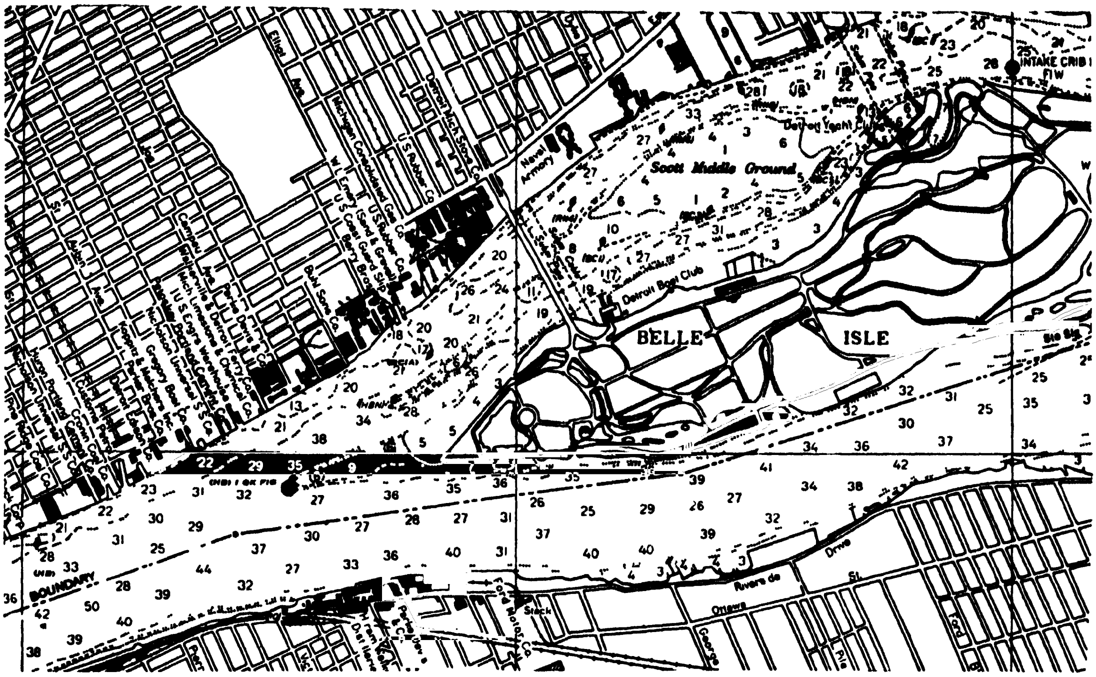


Fig 15–15 Chart of Belle Isle area

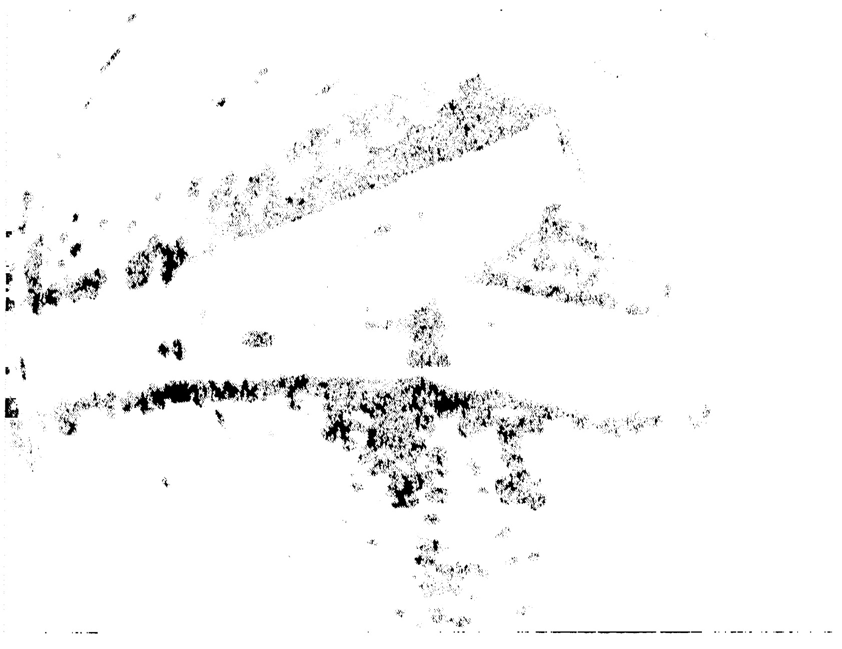


Fig 15–16. An unretouched PPI photograph taken as a ship using the CR-101 radar approached Belle Isle at Detroit, Michigan. The ship is at the center of the picture and is traveling in the direction shown by the heading flash. The rear of the ship may be seen clearly as well as another large ship being passed on the starboard side Two smaller vessels are visible astern (toward the bottom of the picture) at about ¾ mile and 1¼ miles respectively. Range circles on this 1½-mile scale photo are ½ mile apart.

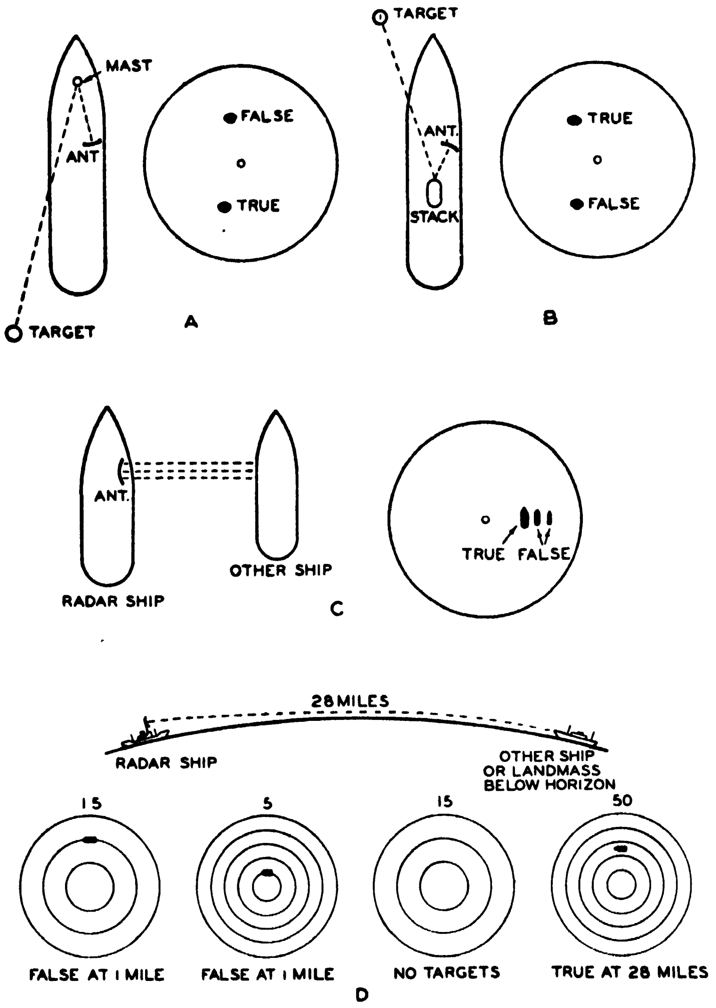


FIG. 15–17. Examples of false or displaced targets.

be set to line up with the heading flash. Then relative bearings against the movable scale, or true bearings against the fixed scale, may be taken.

The true bearing assembly is similar to an ordinary gyro repeater in that it must be reset whenever the ship's master gyrocompass is shut down and then started up again. Resetting was covered in the preceding section, "Operating Procedure." Once set (with the gyrocompass in operation) the TBA will remain in step, regardless of the position of the gyro on-off switch.

Example No. 6. Use of TBA repeater scale: Some navigators may prefer to take true bearings with the movable scale and still have the picture relative to bow (heading flash up). This is done by noting the ship's course on the TBA drum type repeater scale at the top of the indicator and then setting the movable scale. Suppose repeater scale reads 60. Place 60 on movable scale to line up with zero on fixed scale. Then targets are true with respect to the movable scale and relative with respect to the fixed scale.

1. *PPI Photographs.* This book contains a number of PPI photographs taken under actual operating conditions. It may be mentioned that because of limitations in photography, PPI photographs are, in general, less clear than actual targets when viewed directly on the scope.

2. *False or Displaced Targets.* The navigator should become familiar with recognition of false targets that may occur under certain conditions. Refer to the sketch (Figure 15–17) which shows conditions A, B, C and D.

At A, the foremast or other large structures in the path of the beam reflects the beam aft when the antenna points forward. This may cause a target in the rear to appear ahead on the scope. A few seconds later when the antenna does point at the target, it will appear in the correct place on the scope. This effect is easily recognized and depends on the ship's structure, height of radar antenna, size of nearby targets, etc.

At B, a reflection from the stack or other large masses aft of the radar antenna may cause a forward target to appear aft. A little later the target shows correctly forward as the antenna rotates. B is, therefore, the reverse of A, but the general causes are the same.

At C, a near-by ship, or land mass broadside, can act as a very strong reflector. The beam bounces back and forth several times, causing additional targets to appear on the same bearing but displaced in range. The correct target is that nearest your ship.

At D, the effects of abnormally long ranges are shown. Under certain atmospheric conditions, the radar beam may follow the earth's curvature, causing targets to be seen below the horizon. With CR-101 radar this effect may be noted occasionally when using the 1.5 or 5 mile scales *provided* long range conditions exist and targets are distant *more than* 27 nautical or 31 statute miles (approximately).

For example, a target 28 nautical miles distant may appear to be at 1 mile (28–27) on the 1.5 or 5 mile scales. If the target is 30 nautical miles away, it may show at 3 miles on the 5 mile scale (30–27). (The 30 mile target would be "off scale" on the 1.5 range.) Now, by switching to the 50 mile scale the target, if 28 miles away, will appear at its true range.

Long range effects, if observed on the 1.5 or 5 mile scales, may be recognized by watching bearing changes as your vessel proceeds. These changes will be very small compared to normal range targets. Also, by switching to 50 miles, you can check to see if the target exists at the true range. Note that 27 nautical miles (or 31 statute miles) is the "cross-over" point. Targets must exist beyond this point to give false ranges on 1.5 or 5 mile scales.

3. *Bearing and Range Resolution.* Bearing resolution, or the ability of the radar to separate two closely spaced targets at the same range, depends mainly on the horizontal beam width of the antenna. CR-101 horizontal beam is about 1.6° wide at half power points. For purposes of illustration assume the beam is 2° wide and refer to Figure 15–18.

At A assume there are two ships, separated from each other by 400 feet and 1 mile distant from your vessel. The span of a 2 degree beam at 1 mile is about 210 feet and the two ships at this distance are, therefore, separated by more than the beam width. They will appear on the scope as separate targets.

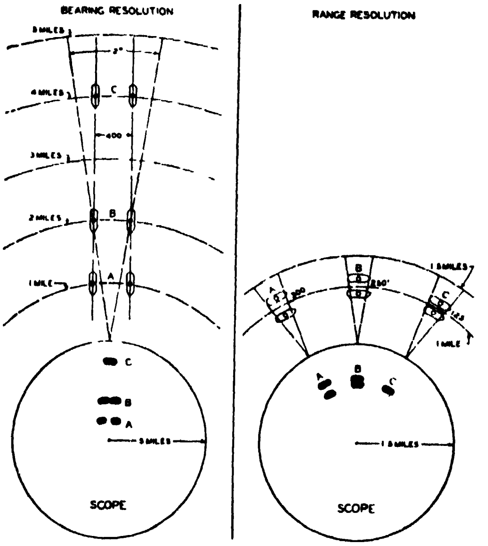


FIG. 15–18. Bearing and range resolution.

Now at B the ships are still 400 feet apart, but 2 miles away. Here the beam is about 420 feet wide, and it is partly on one ship when it intercepts the other ship. On the scope the two ships appear to be touching. At C, 4 miles away, the beam is considerably wider than the 400 foot separation between the ships. In this case a single target shows on the scope.

Therefore, in practice, two or more distant targets that are near one another may blend together and appear as one on the scope. As the range decreases, and with suitable adjustment of the gain control, the targets will separate provided their actual spacing is somewhat greater than the horizontal span of the beam. The approximate span of a 2 degree beam for various ranges in nautical miles is shown below:

Range (miles)	0.5	1	2	3	4	5	10	20	40
Span (feet)	105	210	420	630	840	1050	2100	4200	8400

The span for statute miles is about 16 percent less than above values.

Range resolution is the ability of the radar to separate two targets that are on the same *bearing.* This depends mainly on the pulse length of the radar transmitter for short ranges and mainly on the scope spot size for longer ranges. Since, in practical navigation, we are chiefly interested in seeing closely spaced targets at short range, CR-101 radar uses a 0.25 microsecond pulse for 1.5 and 5 miles. Such a pulse has a "length in space" of 246 feet. Theoretically two ships in line could be seen if separated by 123 feet because the pulse has to make a round trip (twice 123 feet) in going and returning in the space between the ships. However, to provide a safety factor and allow for one target shadowing the other, we say that the range resolution is 80 yards (240 feet) on the 1.5 nautical mile scale.

The separation of in line targets is shown on Figure 15-18. At A, with the two vessels spaced by 300 feet, they appear on the scope as separate targets. At B, with 250 foot spacing, the two ships just merge on the scope. At C, with 125 feet between the two vessels, both appear as a single target.

At greater distances (15 and 50 mile scales) the PPI spot size is the principal factor for range resolution. This gives about 250 yards for 15 miles, 500 yards for 30 miles and so on. The pulse length is 1 microsecond (328 yards) for 15 and 50 mile scales.

15-2h. General Maintenance—This section covers general maintenance of CR-101 radar. Satisfactory operation of the equipment depends, in a large measure, on periodic upkeep such as outlined below. When working on the equipment make sure that the main switch, which supplies power to the radar, is open. As an additional precaution, keep the indicator power switch in the OFF position.

1. *Blower motor:* Transmitter-receiver unit. Lubricate every three months. Accessible by opening the front door of the transmitter-receiver unit and then removing the rectangular screen above the meter panel. Be sure power is off. Place twenty drops of light oil (SAE 20) in each oil hole of the motor.

2. *Blower motor air filter:* Open the small door in lower section of the left panel on transmitter-receiver unit. Examine air filter and if clogged or dirty, discard and replace with a new one.

3. *Antenna drive motor:* Lubricate every six months. Accessible by removing the large end bell from antenna turret. Some motors have grease plugs, while others have oil holes. Use light grease or twenty drops of SAE 20 oil, taking care neither to underlubricate or overlubricate. When replacing end bell be sure all studs are drawn up tightly for a watertight seal.

4. *Antenna turret oil level:* Check oil level by removing upper filler plug. Oil level should be within three-quarters (¾) of an inch from the top. Once each year drain out old oil by removing the lower drain plug. Replace plug and refill with three quarts of SAE 20 motor oil.

5. *Antenna horn:* This is the gooseneck section of the antenna assembly which faces the reflector. The end of the horn is sealed with a rectangular plastic window. This window must ***not be painted.*** The window should be inspected occasionally, and if covered with soot, dirt, or other foreign material, it should be cleaned with a wet cloth. In working around the antenna, care should be taken not to bend or distort the horn or reflector. Correct spacing, measured in a straight line from the surface of the plastic window on the horn to the front edge of one of the reflector rods (just to the right or left of the vertical center rib), is 20$\frac{3}{16}$ inches.

6. *Antenna turret and base flange:* These parts should be painted regularly to avoid corrosion. Aluminum paint is recommended.

7. *Antenna reflector:* The reflector is made of stainless steel and is given a coat of aluminum paint at the factory. After a period of time the reflector may be given another coat of paint for additional protection from corrosion. Do not allow several coats of paint to build up on the reflector.

8. *Main motor generator (on d-c ships) lubrication:* This motor generator uses ball bearings which are properly packed with grease for about six months of normal service. Bearings should be lubricated thereafter at six month intervals. Remove upper and lower grease plugs at each bearing. Force in clean grease at the top until clean grease appears at the drain. Allow the machine to run about fifteen minutes with plugs out to remove grease, then replace plugs, keeping bearings and grease clean. Dirt destroys ball bearings.

9. *Main motor generator (on d-c ships) brushes:* Inspect brushes, commutators and collector rings each time the motor is lubricated. Be sure brushes are free in their holders and wipe away any dirt which may have accumulated on brushes, commutators, or slip rings with a clean cloth. If brushes are worn down, replace them from spares.

10. *Waveguide:* The waveguide run which is exposed to the weather should be kept painted. It is also well to check all waveguide flanges for tightness. The four screws at each flange should be kept tight. Do not allow waveguide to become dented or bent.

15-2i. Tube Replacements—When replacing tubes, refer to illustrations in this book and the list below. Also note that tube sockets are marked to show the symbol number and the tube type number.

1. *Tranmitter-receiver Unit Tubes*

Replacement of these tubes requires a tuning process which is explained in the section "Notes on Magnetron, Local Oscillator, TR and Anti TR," Sect. 15-2j.

The 725-A magnetron should not be touched with power on the set. For maximum safety be sure main power switch in indicator unit is in OFF position and, in addition, open the 15-kv circuit breaker on the control panel of the transmitter-receiver unit.

The magnetron is supported by a circular mounting flange around the glass extension which encloses the high voltage cathode leads. Six screws

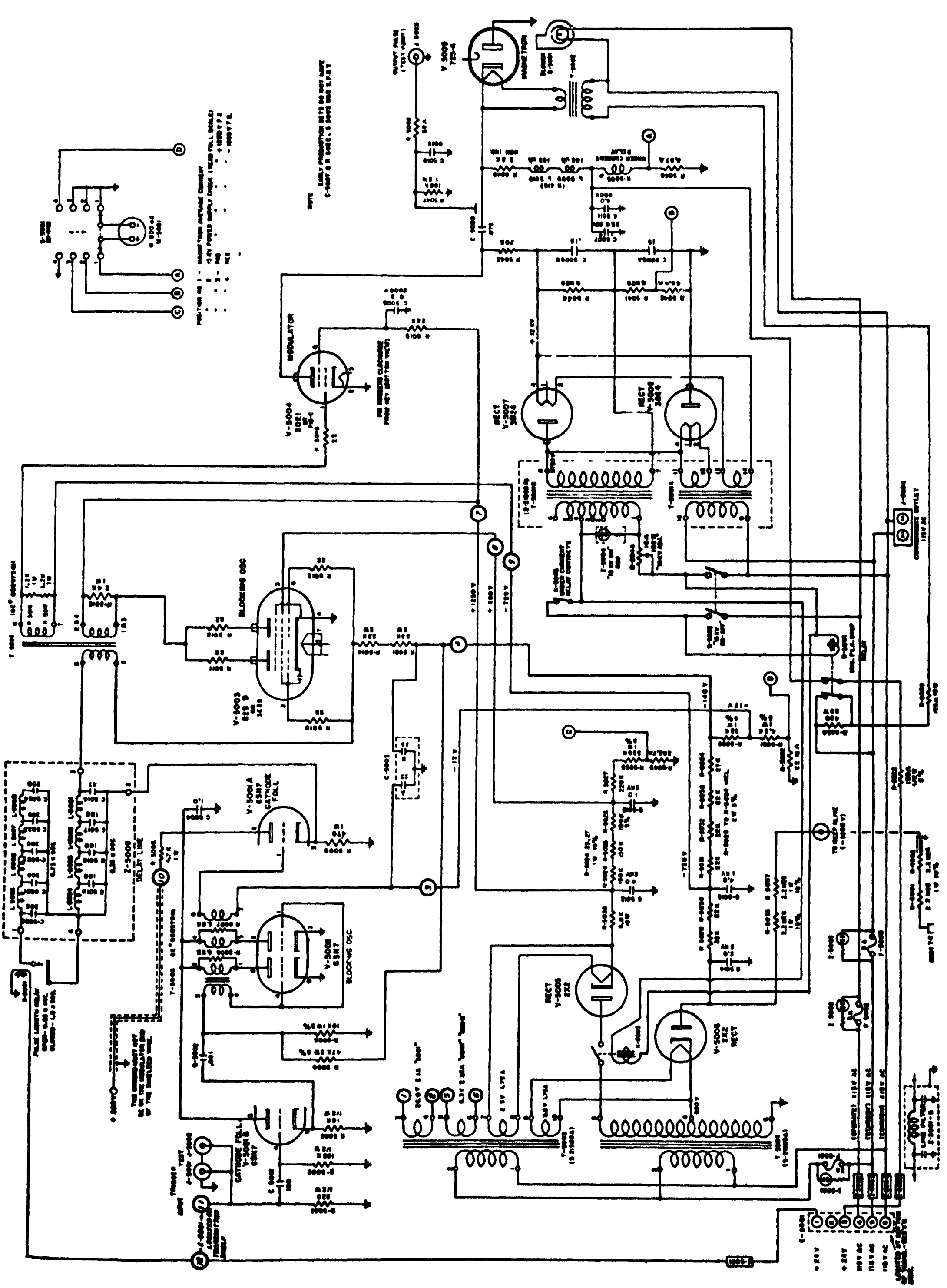


FIG. 15–19. CR-101 radar transmitter schematic.

(A) RECEIVER CHASSIS (IN UPPER RIGHT SECTION)

Symbol	Type	Function	Symbol	Type	Function
V-3002	6AK5	IF	V-3010	6AL5	Detector
V-3003	6J4	IF	V-3011	6AK5	Video
V-3004	6AK5	IF	V-3012	6AG7	Video
V-3005	6AK5	IF	V-3013	6AK5	IF
V-3006	6AK5	IF	V-3014	6AL5	Discriminator
V-3007	6AK5	IF	V-3015	6AK5	D.C. Amp
V-3008	6AK5	IF	V-3016	2D21	F.S. Gen.
V-3009	6AK5	IF	V-3017	2D21	S.S. Gen.
			V-3018	OC3/VR105	Reg.

(B) RECEIVER POWER SUPPLY CHASSIS (BELOW RECEIVER)

V-4001	5R4-GY	Rect.	V-4003	OD3/VR150	Reg.
V-4002	5Y3-GT/G	Rect.	V-4004	OD3/VR150	Reg.

(C) TUBES IN THE MIXER-DUPLEXER ASSEMBLY (UPPER LEFT)

V-3001	723A/B or 2K25	Signal Oscillator (L.O.)
V-3019	1B35	Anti T.R.
V-3020	1B24	T.R.
V-5009	725A	Magnetron

fasten the mounting flange to the support in the transmitter. In addition, the output flange of the magnetron, at the left side of the set, is bolted to the waveguide by means of four vertical studs. Therefore, to remove the tube it is necessary to remove the two flexible cathode leads, the six screws around the circular flange and the four screws around the waveguide flange. The tube should then be withdrawn toward the rear of the set. Do not disturb the four large countersunk screws at the front of the set, as these support the magnet.

To install a new magnetron, reverse the above procedure but do not tighten any of the screws until it is certain that the circular indentation of the anode block (1 inch square block attached to the fins) is centered between the poles of the magnet. Carefully tighten all screws, keeping the magnetic center of the anode block precisely between the poles of the magnet. When working around the magnetron or its permanent magnet, do not permit screwdrivers, pliers etc., to come in contact with the pole faces of the magnet. Carelessness in this respect may alter the field strength of the magnet. Iron filings or other magnetic material tend to accumulate around the pole faces and should be removed when replacing a magnetron.

(D) CRYSTALS IN THE MIXER-DUPLEXER ASSEMBLY

There are two crystals, each type 1N23B. They are located as shown on Figure 15–21 and are shielded by a screw type cover having a long shaft at the top. After removing the cover, pry out the crystal with a knife blade. (Later duplexers use a special tool with two spaced prongs which fit into the crystal cap for unscrewing and removing crystals.)

(E) TRANSMITTER TUBES (BEHIND PERFORATED HIGH VOLTAGE PANEL)

(*Caution:* High Voltage! Never remove perforated panel or touch any tubes inside unless main line switch is open or indicator power switch is in "off" position.)

Symbol	Type	Function	Symbol	Type	Function
V-5001A	(one half of 6SN7)	Cath. Foll.	V-5005	2X2	Rect.
V-5001B	(other half of 6SN7)	Cath. Foll.	V-5006	2X2	Rect.
V-5002	6SN7	Block Osc.	V-5007	3B24	Rect
V-5003	829-B (3E29)	Block Osc.	V-5008	3B24	Rect.
V-5004	5D21 (715C)	Modulator			

2. *Indicator Unit Tubes.* Access to indicator tubes is accomplished by loosening the four hexagon head studs on front of unit and then sliding out the assembly on the rollers and tracks provided. When assembly is pushed back into binnacle, take care that the flexible cables inside do not become fouled.

(A) SYNCHRONIZER CHASSIS (TUBES FACE TOWARD REAR)

(*Note:* A and B denote each half of dual type tubes.)

Symbol	Type	Function	Symbol	Type	Function
V-1001A–B	6SN7	Mas. M.V.	V-1010A	6SN7	Shaper
V-1002A	6SN7	Pul. Inv.	V-1010B	6SN7	Inv.
V-1002B	6SN7	D.S. Gen.	V-1011A	6SN7	Block Osc.
V-1003A	6SN7	D. Clamp	V-1011B	6SN7	C.F. Lim.
V-1003B	6SN7	D. C. F.	V-1012A	6SN7	S.T.C. Gen.
V-1004A	6SN7	D. Amp.	V-1012B	6SN7	S.T.C. Lim. C.F.
V-1004B	6SN7	D. Amp.	V-1013	6AK5	Video
V-1005A	6SN7	Inv.	V-1014	807	Video
V-1005B	6SN7	Sq. Amp.	V-1015A	6SN7	Sw. Gen.
V-1006	2D21	Trig. Gen.	V-1015B	6SN7	Sw. Amp.
V-1007	2D21	Hdg. Fl.	V-1016A	6SN7	Unblkg. C.F.
V-1008	6SJ7	Focus	V-1016B	6SN7	Sw. Inv.
V-1009A	6SN7	R.M. Osc.	V 1017	807	Video
V-1009B	6SN7	R.M. Amp.	V-1018	807	Video

(B) SYNCHRONIZER POWER SUPPLY (VERTICAL TUBES LOWER REAR)

V-2001	5R4-GY	Rect.	V-2005	6SJ7	Reg.
V-2002	5R4-GY	Rect.	V-2006	OC3/VR105	Reg.
V-2003	6AS7-G	Reg.	V-2007	5Y3-GT/G	Rect.
V-2004	6AS7-G	Reg.	V-2008	OD3/VR150	Reg.

(C) SYNCHRONIZER 5 KV POWER SUPPLY (BEHIND SYNCHRO CHASSIS)

This unit uses one 3B24 (RK72) tube, symbol V–2101.

Caution: High Voltage! Power must be off when replacing this tube.)

The 3B24 tube is mounted inside a rectangular metal box which has a cover plate held by four thumb screws. Reach through right side of binnacle assembly to remove cover when replacing tube.

(D) PPI TUBE—V-2301—TYPE 12DP7A

To replace this tube follow carefully the procedure outlined below.

Turn set to OFF to remove all power. Extreme care must be observed whenever the cathode ray tube is handled. The large surface area of the tube has atmospheric pressure against it, and breakage will cause glass and tube elements to scatter dangerously. Use both hands when lifting the CRT. and never lay it down on hard surfaces. Transfer the tube from its special carton directly to the indicator unit as follows:

1. Remove the female octal socket from the base of the CRT.
2. Disconnect the CRT 5000-volt anode lead. This flexible lead will be found at the left side of the tube shield and connects to the 5000-volt rectifier unit.
3. Open the hinged panel on the top front of the binnacle which houses the glass CRT light filter and the various CRT scales. This can be accomplished by turning the screw, directly above the range ring control, counterclockwise. The entire assembly can then be raised on hinges so that it opens out and to the left.
4. Remove the screws around the circumference of the cathode ray tube to remove the holding shock absorbing ring.
5. The CRT can now be lifted out of the CRT shield assembly by gently pushing up on the tube base. Another person should be engaged to lift the face of the tube at the same time. Take care not to force the tube. Lift the tube out along the long axis of the CRT, and make certain that the accelerating anode cap on the side of the tube clears the hole admitting its cap.
6. Place the defective tube in the carton which came with the new tube.
7. To insert the tube, reverse the above procedure. Caution should be exercised in screwing down the holding shock absorbing ring. Tighten all screws equal amounts until the sponge is compressed and the CRT is firmly seated. Do not force any of the adjustments. If binding occurs, investigate the reasons before continuing. Do not drop tools on the face of the tube. Exercise caution.
8. After inserting a new CRT, check the height of the tube face so that it does not touch the cursor wire. It may also be necessary to recenter the spot on the tube by using the three knurled adjusting screws near the base end of the shield assembly. These screws determine the physical position of the focus coil. Proceed as follows:
9. Turn MAIN POWER SWITCH to OPERATE. Turn GAIN CONTROL fully counterclockwise. Use 15 mile range and advance the INTENSITY CONTROL until the sweep is clearly visible. The center of the sweep should be at the physical center of the tube. Use the cursor wire at 0 and 90 degrees to check this. Then make small adjustments on the three knurled screws to exactly center the sweep.

3. *Fuse Replacements.* Blown fuses should always be replaced with the same rating as those furnished with original equipment. All fuses (except those in the main line fused switch) are provided with indicator lights. When a fuse blows the indicator light will glow. Replacement with a new fuse will extinguish the light. All fuses (except in main line) are glass type mounted in insulated holders for front panel replacement. To remove, turn fuse cap to the left and withdraw. Insert new fuse of correct rating in cap and replace in holder.

4. *Replacement of Dial Lights.* Sixty-volt switchboard lights No. 902 are used for "range" and "power on." Replacement tools (special pliers and lamp extractor) are clamped inside binnacle at top rear. With pliers, remove glass cap over light Insert lamp extractor, press brass clamper to grip bulb and withdraw. Insert new bulb, keeping it straight so that it makes proper contact in socket. Replace glass cap.

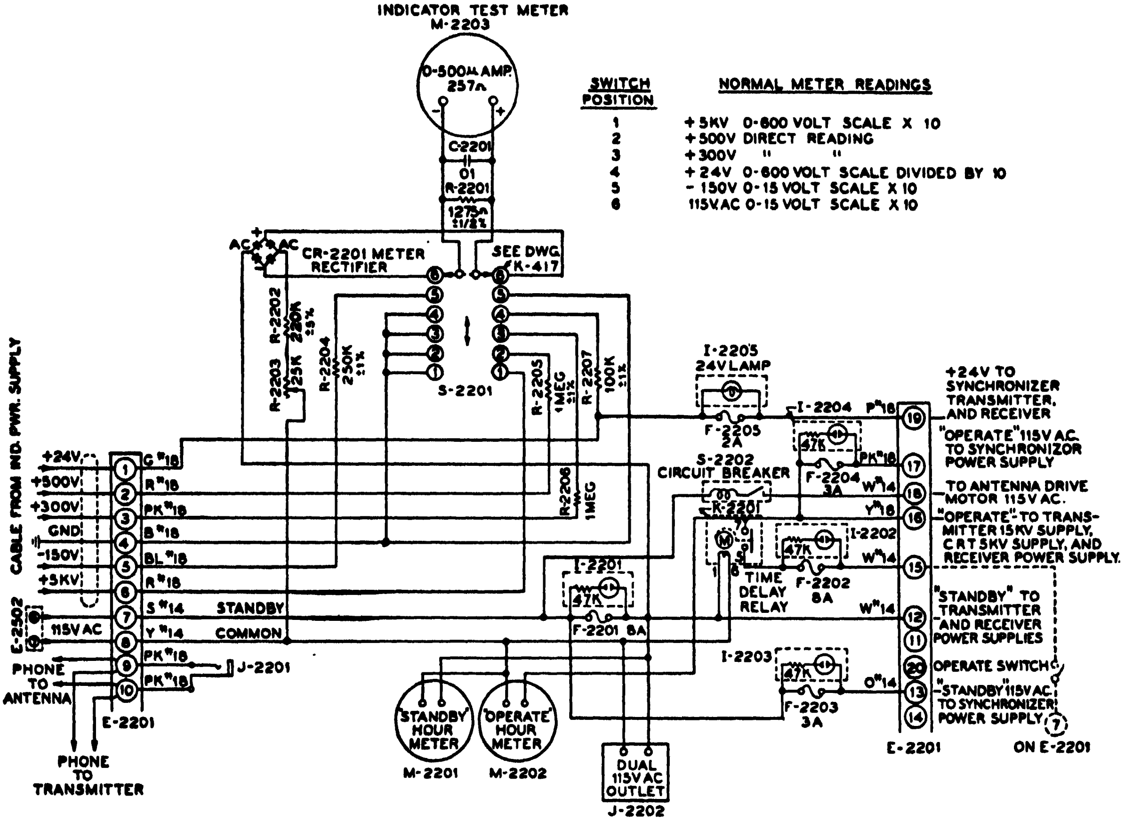
The indicator azimuth scale uses six Mazda No. 323 lamps (3 v). These are "midget" bulbs with black knurled screw bases. Two are located on outside rim of scale housing. The other four are inside, accessible by opening hinged scale housing. Take care not to drop tools on PPI tube or damage cursor wire when working on inside of housing.

5. *Built-in Test Meters.* There are three test meters mounted in the equipment to provide a convenient means for checking various voltages and currents. These meters are located (1) in the lower section of the indicator, (2) in the lower section of the transmitter, (3) on the receiver chassis itself. Each meter has two scales marked 0–15 and 0–600. The 0–15 scale is referred to as the upper scale and the 0–600 as the lower scale. Each meter is provided with a switch which connects the meter to the appropriate circuit and also inserts the proper value of shunt or series resistor to read the desired voltage or current. When using these meters to check the performance of the equipment, refer to the following tabulation. The references to "scale" means the lower or upper scale of the meter. The "factor" means that the meter reading is multiplied or divided as indicated to give actual values.

INDICATOR TEST METER

Meter Switch	Scale	Typical Reading	Actual Value	Factor
5 kv	Lower	440-600	4400-6000 v	×10
500 v	Lower	450–550	450–550 v	×1
300 v	Lower	290–310	290–310 v	×1
24 v	Lower	220–260	22–26 v	÷10
−150 v	Upper	14–16	140–160 v	÷10
115 v a.c.	Upper	11–12	110–120 v	×10

Note: The 115 volt a-c position of the meter switch shows the a-c line voltage which furnishes power to the entire radar equipment.



SWITCH POSITION	NORMAL METER READINGS
1	+5KV 0-600 VOLT SCALE X 10
2	+500V DIRECT READING
3	+300V " "
4	+24V 0-600 VOLT SCALE DIVIDED BY 10
5	-150V 0-15 VOLT SCALE X 10
6	115V AC 0-15 VOLT SCALE X 10

FIG. 15–20. CR-101 radar indicator fuse panel circuits.

TRANSMITTER TEST METER

Meter Switch	Scale	Typical Reading	Actual Value	Factor
Mag. ma	Upper	7.5	7.5 ma	×1
15 kv	Upper	12	12 kv	×1
+1250 v	Upper	12–13	1200–1300 v	×100
−1000 v	Upper	9–11	900–1100 v	×100

Note: Mag. ma position will also read about 7.5 when 15-kv circuit breaker is OFF, or when 15-kv source has failed. Disregard this reading as it is due to current through the undercurrent relay coil which exists before magnetron current flows.

RECEIVER TEST METER

Meter Switch	Scale	Typical Reading	Actual Value	Factor
+300 v	Lower	280–320	280–320 v	×1
+105 v	Upper	10–11	100–110 v	×10
−300 v	Lower	280–320	280–320 v	×1
+24 v	Lower	220–260	22–26 v	÷10
Rec'r Xtal I	Upper	3–5	0.3–0.5 ma	÷10
AFC Xtal I	Upper	3–5	0.3–0.5 ma	÷10

15–2j. Notes on Magnetron, Local Oscillator, TR and Anti-Tr—One of the most common service operations for the CR-101 radar involves replacement of tubes or crystals that are mounted in the duplexer-mixer assembly (referred to as "duplexer" hereafter). When these items have reached the end of their normal life and are replaced with new ones, retuning is necessary to keep the overall system operating at maximum efficiency. This work will be facilitated if there is a clear understanding of the general circuit theory.

Refer to Figure 15–21. The 725–A magnetron is coupled to the lower end of the duplexer. The nominal center frequency of the 725–A is 9375 mc. Production magnetrons may vary plus or minus 30 mc, which means that the actual frequency can fall between 9345 and 9405 mc. In addition, the magnetron frequency may be "pulled" by the load drawn from it and by temperature changes, to the extent of about 25 mc. These factors establish a total plus or minus variation of 55 mc, which makes the radar frequency band 110 mc wide or 9320 to 9430 mc. Therefore, changing a magnetron requires retuning as explained further in this section.

When the magnetron output passes up the duplexer, it is necessary to protect the receiver crystal from burnout. This is the function of the 1B24 T-R tube (T-R means transmit-receive). The 1B24 is a resonant cavity spark gap type of tube with a "keep alive" electrode. The keep alive electrode has maintained on it minus 1000 volts d.c.

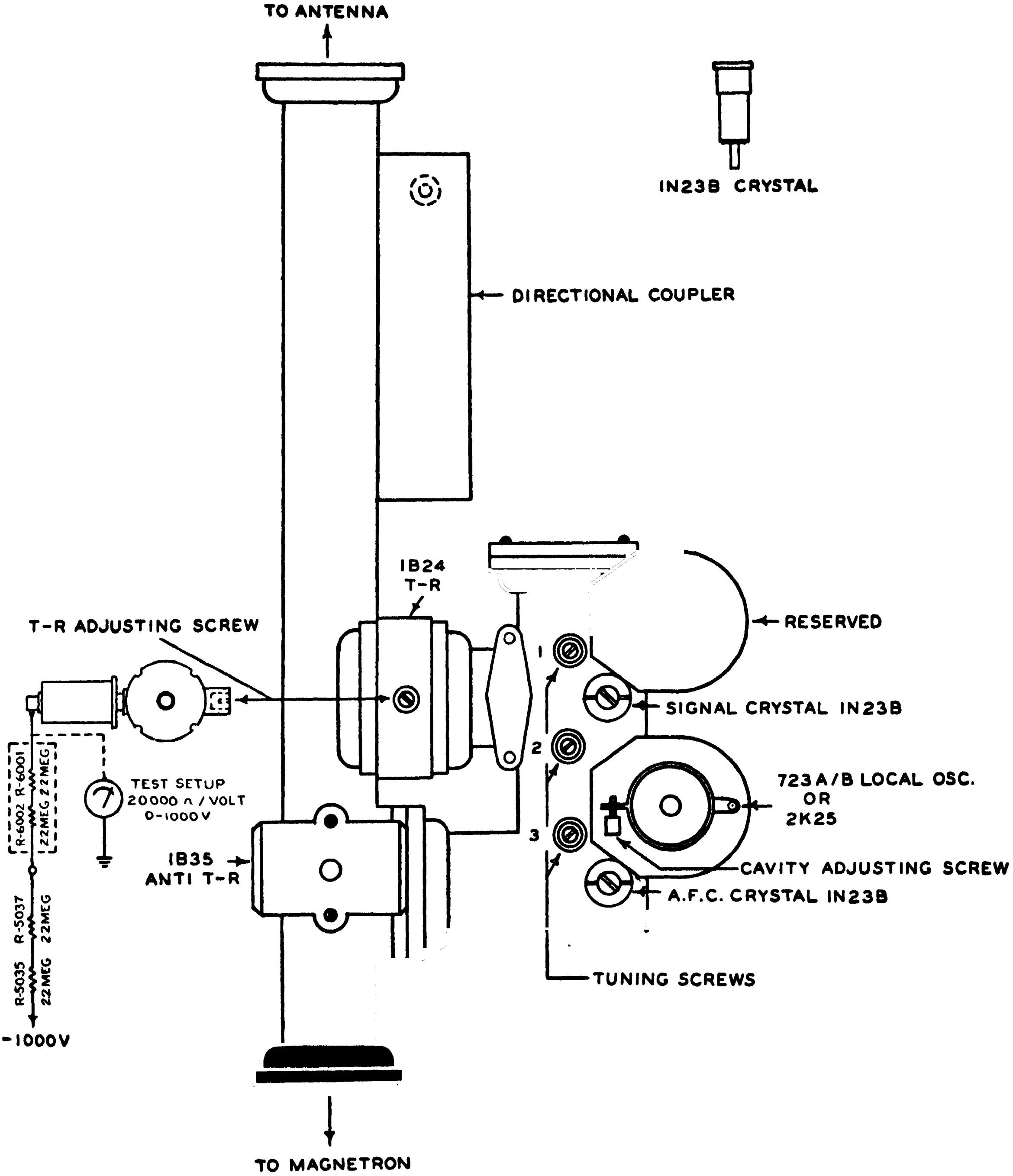


Fig. 15–21. CR-101 duplexer.

(through high resistors), so that the 1B24 cavity will arc over quickly each time the magnetron pulse occurs. The arc detunes the cavity and produces a short across the input to the receiver crystal in the mixer section. A small amount of power does leak through but is not sufficient to damage the crystal when the T–R tube is in good condition.

Each time the magnetron pulse ceases, the 1B24 arc stops, which opens the path to the crystal and allows the receiver to function. The adjusting screw on the front of the 1B24 is used to tune its cavity to the incoming signal, which of course has the same frequency as the outgoing magnetron pulse. When the 1B24 ages, its arc-over voltage tends to increase, which may result in damage to crystals or the recovery time may lengthen causing close in targets to be obscured. The 1B24 may be checked by measuring the voltage from the keep alive electrode to ground. Use a 20,000 ohm per volt (not 1000 ohms) meter as the voltage must be measured right at the keep alive electrode which has several megohms in series from the 1000 volt supply. The transmitter may be on or off and the 1B24 should be checked as follows:

New or little used tube: 325 to 450 volts.

Used tube: 325 to 600 volts. Replace if voltage is below or above these limits or close to them. Retune 1B24 as described later.

The anti T–R tube, 1B35, does not use a keep alive electrode, and has no adjustments for its cavity. This tube automatically presents a low impedance to the outgoing pulse when transmitting, and high impedance to the received signal when receiving. This arrangement keeps the incoming signal from passing into the magnetron cavity, which would reduce receiver sensitivity. The 1B35 anti T–R tube should be changed after approximately 1000 hours of operate time.

Whenever a T–R, anti T–R, or magnetron is replaced the service man should fill in the tag attached to the duplexer assembly to show:

1. Hour reading of "operate" meter.
2. Type of tube or tubes replaced.
3. Date, port, and name of service man.

This information will assist the next service man to check the number of hours the tubes have been in use and to determine if other tubes in the duplexer need replacement.

The radar receiver is a high-gain superheterodyne with 30-mc intermediate frequency and, therefore, requires a local oscillator to beat with the magnetron frequency and a signal crystal to act as a mixer or first detector. The local oscillator, a 723A/B or 2K25 tube (klystron) and the signal crystal 1N23B are mounted in the right hand or mixer section. The tuning screw marked "2" adjusts the r-f coupling between the local oscillator and the signal crystal. There is a second 1N23B crystal, known as the AFC crystal, whose r-f coupling between the same local oscillator and the AFC crystal is adjusted by tuning screw marked "3." Tuning screw "1" and a mounting for a second 723A/B oscillator are for future beacon or "Ramark" operation and are not discussed in this book. Before describing the adjustment procedure for tuning screws 2 and 3, the action of the 723A/B local oscillator should be understood.

The local oscillator is a cavity type of tube and must operate 30 mc *above* the magnetron frequency in order to permit the automatic frequency control (AFC) circuits in the receiver to function. For example, if the magnetron is running at 9375 mc, the L.O. (local oscillator) must function at 9405 mc. There are two controls for the 723A/B frequency. One control is a square head screw on the tube, underneath the shield cover, which "squeezes" the tube cavity strut to change its resonant frequency. Highest L.O. frequency is with the strut fully closed, screw turned left all the way. This screw causes the frequency to *decrease* when turned toward the *right* and is used for comparatively *large* changes in frequency. The square head screw and the metal *tube envelope* have 300 volts impressed on them and the special tuning tool (Plastic Rod, socket on one end, screwdriver on other end) must be used for adjustment.

The second local oscillator control, for *small* changes in frequency, is located on the receiver chassis, near the top front section. This control, a potentiometer, is used to adjust the reflector electrode voltage of the 723A/B. A MANUAL-AFC toggle switch on the receiver chassis is used in the MANUAL position for initial adjustments (described later). It is then left in the AFC position for normal operation so that the receiver AFC circuits can control the 723A/B reflector voltage and hence its frequency. There is also a second MANUAL-AFC switch on indicator lower panel. This switch must be left in the AFC position when adjusting the receiver and for normal service. In an emergency the switch on the indicator panel can be used in the MANUAL position and the MANUAL TUNE shaft adjusted for best targets on PPI. This would be done in case the receiver AFC tubes or circuits fail.

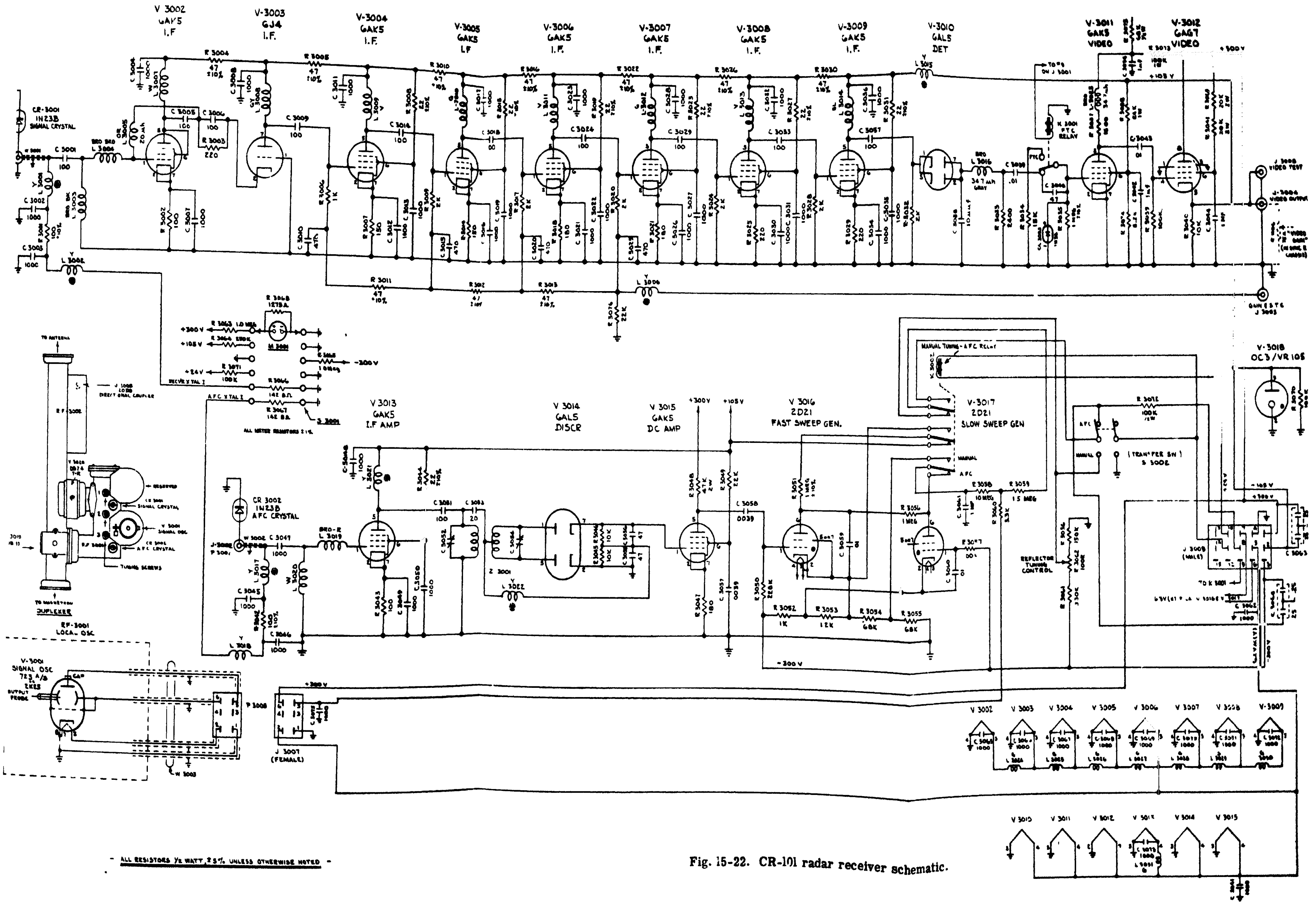
A review of the foregoing theory will make it clear that retuning in the duplexer assembly is needed to take care of the following conditions:

1. A new 725–A magnetron requires cavity and reflector voltage adjustments to the 723A/B oscillator, tuning of screws 2 and 3, and retuning of T–R.
2. A new 723A/B local oscillator requires cavity and reflector voltage adjustments and tuning of screws 2 and 3. (Similar routine as in 1.)
3. A new 1B24 T–R replacement only, requires retuning of its cavity adjusting screw.

The above tuning operations are best accomplished by using a type TS–34A/AP synchroscope. This unit functions as an A scope to show the relative amplitude of received signals. It is also useful to observe wave forms in checking trouble at the tube sockets or other circuit elements.

The mechanical procedure for replacing a 725–A magnetron has already been described. When applying power to a new tube, a gradual process should be used as follows:

Open the 15-kv circuit breaker (indicator unit power switch to be in OPERATE position). Turn 15 KV ADJ screw (rheostat control) full counterclockwise. Place TRANSMITTER METER switch in position 1 to read magnetron plate current. Close 15-kv breaker. *Warning:* Do not touch high-voltage magnetron cathode leads, filament transformer, or other high potential components. Allow



- ALL RESISTORS ½ WATT ±5% UNLESS OTHERWISE NOTED -

Fig. 15-22. CR-101 radar receiver schematic.

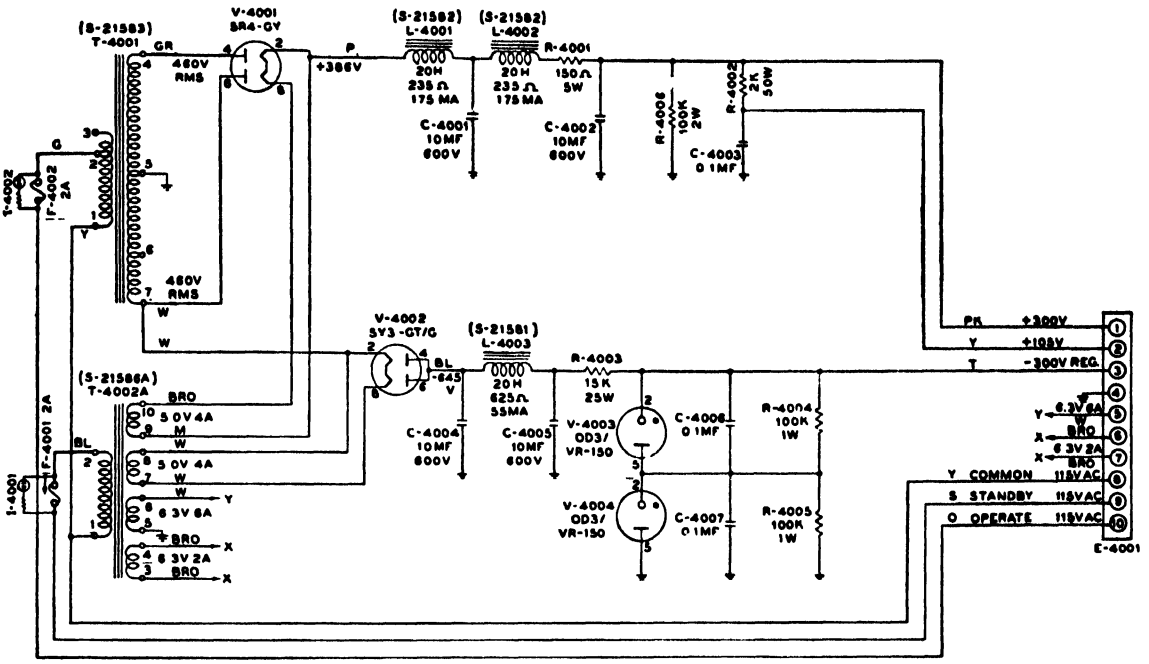


FIG. 15–23. CR-101 radar receiver power supply.

tube to operate for at least 5 minutes. Gradually raise voltage with 15-kv screw and listen for arcing inside tube. If arcing occurs, lower voltage and then slowly increase it. It is normal for some new tubes to arc until they are seasoned, but long period arcing at high voltage must be avoided. Finally, when the tube is operating correctly, adjust the 15-kv screw until the magnetron current is 7.5 ma. A check may then be made on magnetron voltage (switch position 2) which should indicate about 12 kv.

15-2k. Arrangement of TS34A/AP Synchroscope

1. *General*

(a) Refer to Figure 15–24 showing TS34A/AP connected to transmitter-receiver unit.

(b) Plug in a-c cord to receptacle on transmitter test panel.

(c) Connect synchronizing cable to trigger test jack on transmitter test panel. Use probe assembly MX–474/AP or MX–50/AP.

(d) Connect SIGNAL INPUT cable to video test jack in end of receiver. Use probe assembly MX–474/AP or MX–50/AP.

2. *Scope Settings*

(a) Input impedance: Set on "0."

(b) Image size: Turn all the way clockwise.

(c) Attenuation: Set on "0."

(d) Sync switch: Set on EXT.

(e) Sync voltage: Adjust to obtain steady picture.

(f) Sync. polarity: Switch down.

(g) Sweep selector: On START-STOP.

(h) Sweep speed: COURSE set to SLOW. FINE adjust to give suitable picture size.

(i) Position controls: Horizontal set to about center. Vertical set to about center.

3. *Test Conditions for Retuning if 725–A Magnetron or 723A/B Local Oscillator is Replaced*

(a) Antenna stopped (antenna switch off) with antenna pointing in direction of targets.

(b) POWER switch on OPERATE. Range 1.5 or 5 miles, depending upon targets available. RECEIVER GAIN adjusted so that noise pips (grass) appear on A scope.

(c) RECEIVER METER switch at 5 to read signal crystal current (later this switch is used at 6 to read AFC crystal current).

(d) RECEIVER AFC-MANUAL switch at MANUAL (INDICATOR AFC-MANUAL switch kept on AFC).

(e) Shield cover removed from 723A/B local oscillator so that plastic tuning wrench can be used to adjust cavity square head screw (300 volts on tube shell and screw).

(f) There are two settings of 723A/B local oscillator cavity screw which will give maximum signals. One is 30 mc below and the other 30 mc above the magnetron frequency. The higher setting is the *only* correct one which permits the AFC circuits to lock in. With the screw turned all the way to the left (counter clockwise looking up at screw head), the strut is fully closed. This gives the ***highest*** local oscillator frequency. As the screw is slowly turned to the right (clockwise), the first signals seen

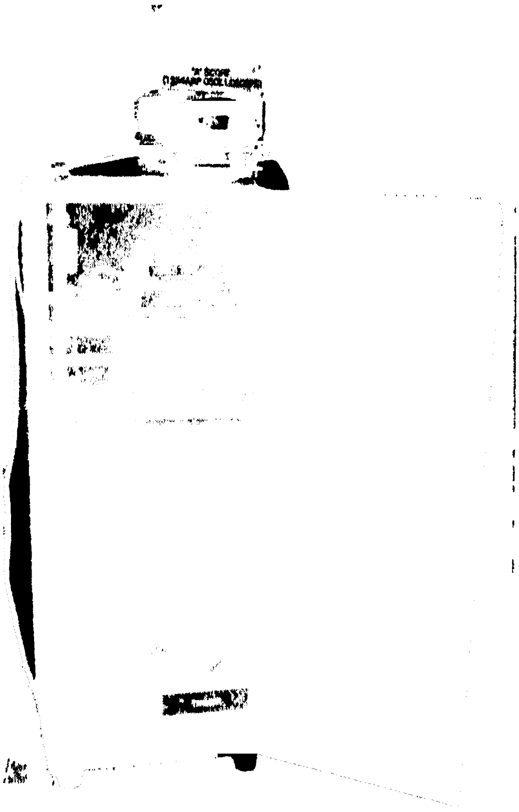


FIG. 15-24. RCA CR-101 radar test set-up using TS34A/AP oscilloscope.

on the "A" scope are the signals to be used for *correct* AFC operation. Turning the screw still more to the right will cause signals to first disappear and then reappear at the point where the local oscillator is 30 mc below the magnetron frequency. This is an *incorrect* setting. In other words, it is best to start out with the local oscillator running at its highest possible frequency (strut closed) and then use the first set of signals which appear when the screw is turned to the right.

(g) Set the local oscillator on its highest frequency by closing the strut (screw turned fully left).

(h) Adjust reflector voltage by the potentiometer on the receiver chassis to give some crystal current, but not over 0.5 ma.

(i) Turn local oscillator tuning screw gradually to the right watching for signals on the A scope, and also note that there is some crystal current at all times. Be sure local oscillator is running 30 mc high as explained in paragraph (f).

(j) When signals appear, adjust first the reflector potentiometer and then cavity tuning screw until maximum crystal current is obtained when maximum signals are observed. Maximum current and A scope signals should coincide.

(k) Adjust tuning screw 2 to give about 0.4 ma. This current should be between 0.3 and 0.5 ma.

(l) Next place meter switch at 6 to read AFC crystal current. Adjust screw 3 so that AFC current is between 0.3 and 0.5 ma. Do not vary reflector or local oscillator cavity screw. Adjustment of screw 3 may change receiver crystal current (switch position 5). Check this and readjust screw 2, if necessary. Repeat adjustments of both 2 and 3 screws so that any interlocking between them is equalized.

(m) Defective crystals will cause low crystal current and poor receiver sensitivity. Crystals are exposed by unscrewing the long shaft (shielding) and then by carefully prying out the crystal.

(n) Now check for proper AFC operation. Throw AFC-MANUAL switch on receiver chassis to AFC and leave it there. Start antenna and observe signals on PPI. Also note that receiver and AFC crystal currents show steady values on the meter. Change MAIN POWER switch from STANDBY to OPERATE a few times. Replace shield cover on 723A/B local oscillator with power off. (*Note:* AFC circuit may also be checked for "sweeping" action. Open 15-kv breaker and note that crystal current in positions 5 and 6 rises and falls slowly.)

(o) Retune T-R to give maximum signals on A scope after replacing magnetron.

4. *Tuning Procedure for 1B24 T-R Tube.* If the TS34A/AP scope is set up, the 1B24 T-R tube is tuned by simply adjusting its cavity screw for maximum signals on the A scope. An alternative method, which can be used if an A scope is not available, is to adjust the 1B24 cavity screw while someone observes the intensity of signals on the PPI. Correct screw adjustment will be shown by brightest signals on the PPI.

15-3. Loran [2]—The Loran system is a modern electronic aid to navigation by means of which navigators on or over the ocean can determine their position accurately and quickly, day or night, and under practically any condition of weather and sea. The name "loran" was derived from the words "*LO*ng *RA*nge *N*avigation," which describe in general terms the system's relative utility when compared to ranges of other electronic navigational aids. The effective range of loran is as great as 1400 nautical miles at night and 750 miles during the day (Figure 15-27). The accuracy obtained is comparable to that which may normally be expected from good celestial observations. Even though such precision is attained, the determination of position by loran requires but 2 to 3 minutes' time.

The navigator can think of loran as merely a new method of determining lines-of-position. These loran lines can be crossed with other loran lines, with sun lines, star lines, soundings, radar range

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[2] This entire section on loran reprinted from U. S. Coast Guard Publication "Electronic Navigational Aids" by permission.

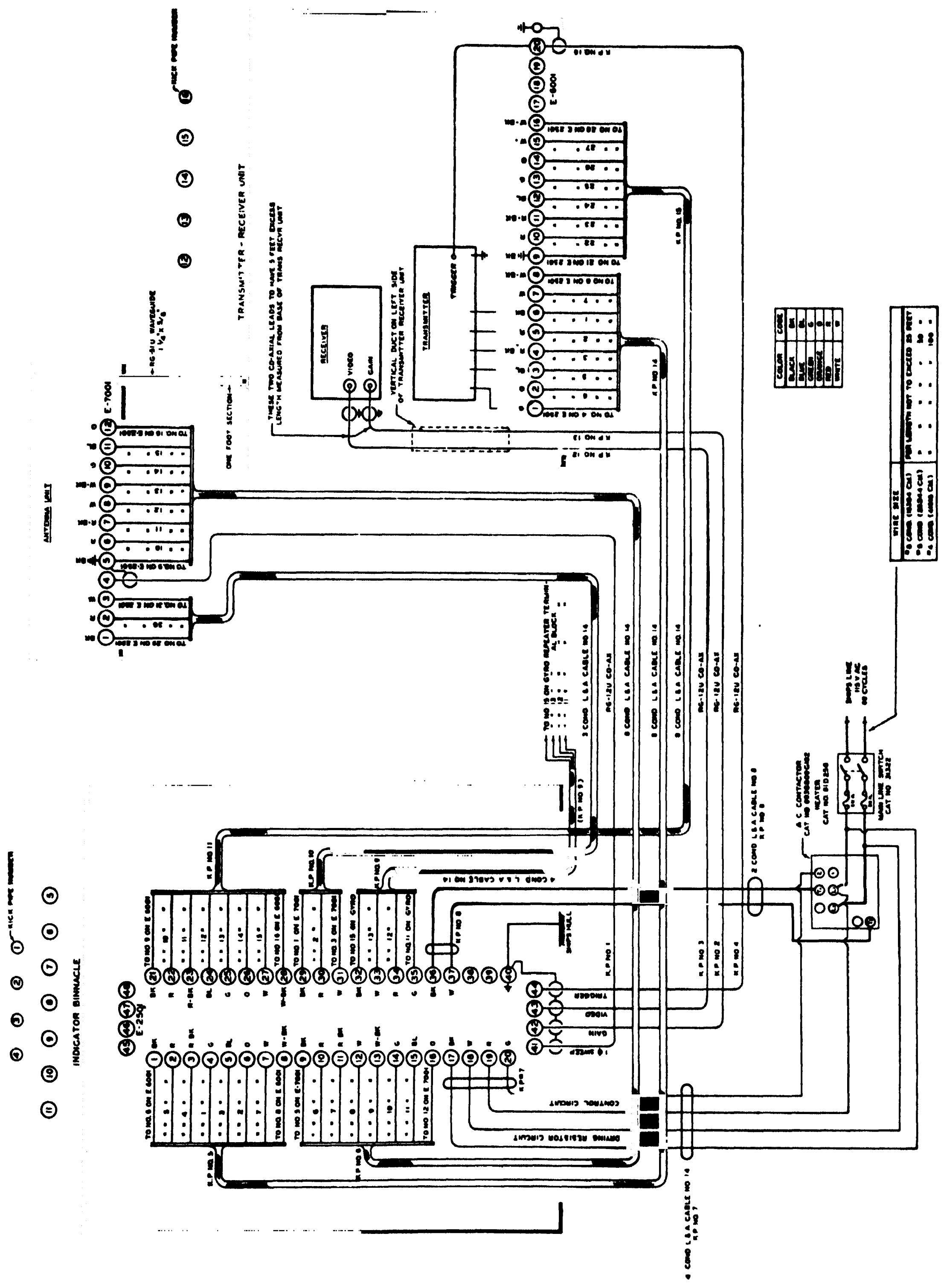


FIG. 15-25. CR-101 radar external connection diagram for 115-volt, 60-cycle power supply.

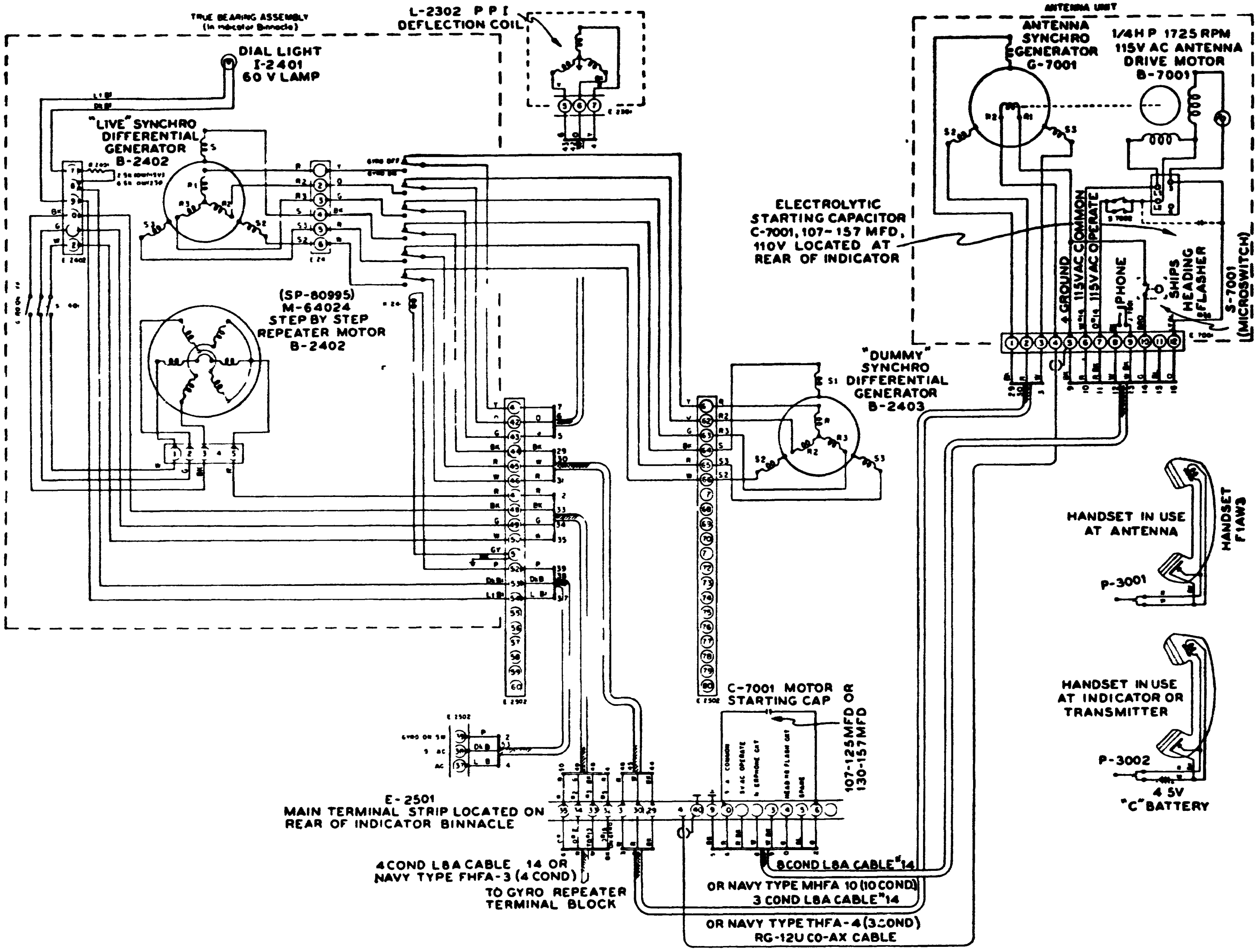


Fig 15-26 Radar synchro system

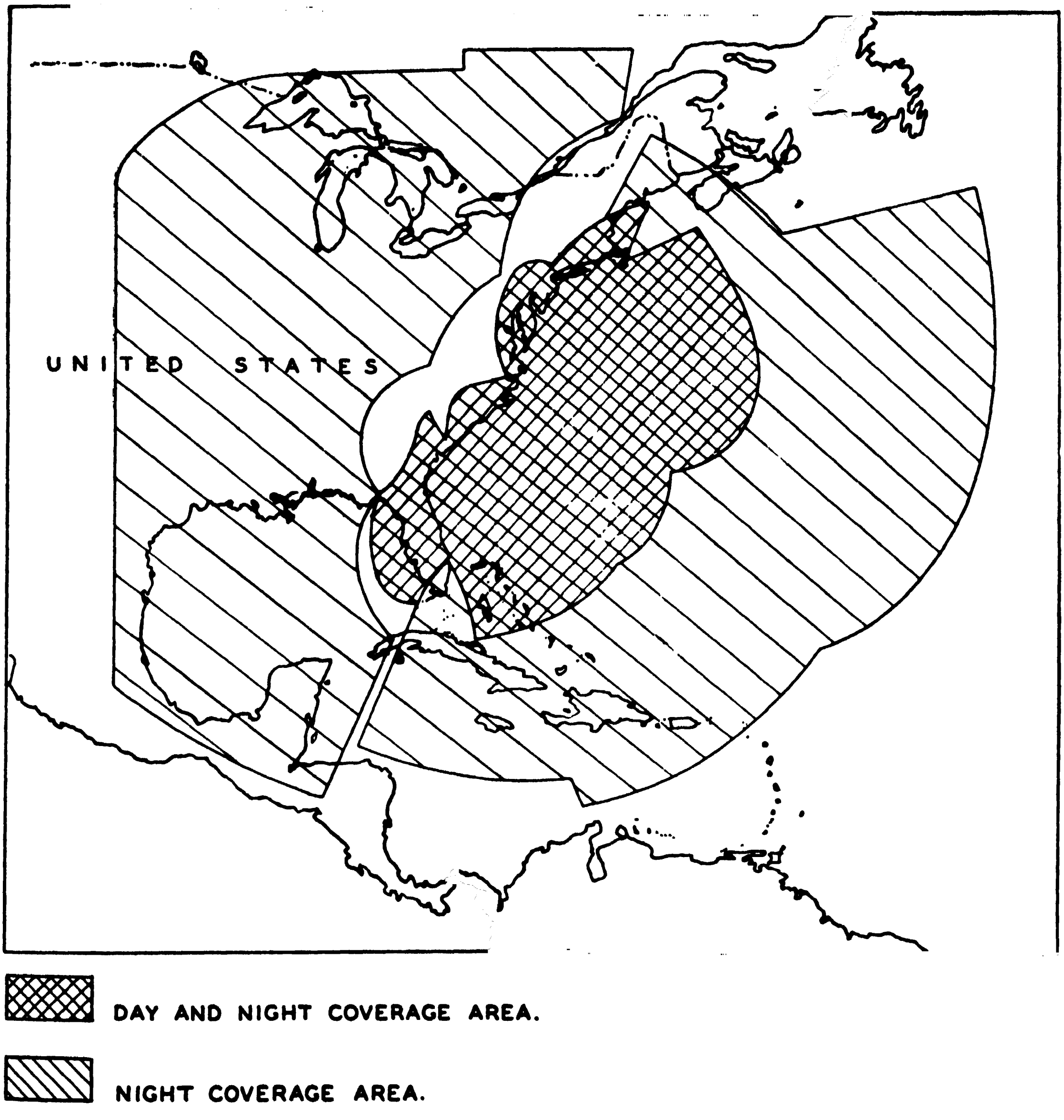


Fig. 15–27. Typical day and night loran coverage area.

circles, or bearings, to provide fixes. Loran lines are fixed with respect to the earth's surface; their determination is not dependent upon the ship's compass, chronometer, or other mechanical or electronic devices. Loran shipboard equipment requires no special calibration and is not affected by the arrangement or disarrangement of shipboard antennas, cargo booms, ventilators, etc., as in the case of radio direction fingers.

Loran signals are on the air and available to navigators for 24 hours per day, and cover the major shipping lanes of the seas and oceans of the world. Developed as a wartime necessity, the system is now at the disposal of private shipping—any nation, any line, all may make free use of it.

15–3a. Principles of Operation—Loran operates on the following principles:

1. Radio signals consisting of short pulses are broadcast from a pair of shore-based transmitting stations.
2. These signals are received aboard the ship or plane on a special loran radio receiver.
3. The difference in times of arrival of the signals from the two radio stations is measured on a special loran indicator.
4. This measured time-difference is utilized to

determine directly from special tables or charts a line-of-position on the earth's surface.

5. Two lines-of-position, determined from two pairs of transmitting stations, are crossed to obtain a loran fix.

Since radio signals travel at a constant speed, the direct relationship between time of travel and distance traveled exists. Thus, measurement of intervals of time is, in essence, a measurement of distance itself.

The radio signals which are transmitted by loran stations are not continuous transmissions such as those of everyday commercial broadcasting stations, but are "pulse" signals, or short bursts of radio energy transmitted at regular intervals. The use of "pulse" signals permits the individual signals to be identified in order that time measurements can be made. This would not be possible if the transmissions were continuous.

Because the basic loran measurement evaluates the difference in the distance between the navigator and each of two fixed transmitting stations and not the individual distances themselves, there are many points at which the difference would be the same even though the distances varied widely. These points fall along a smooth curve (hyperbola) which is known as a loran line of position. Therefore, when a navigator has obtained a loran reading from a pair of transmitting stations he has determined that his true position lies at some point on a particular loran line of position. By making loran measurements on a second pair of stations a second line of position has been identified and the navigator's true position or "fix" has been established at the point of intersection of the two lines.

In order to simplify the navigator's problem of interpreting the loran data in terms of coordinates of latitude and longitude, loran charts are provided which picture the electronic lines of position with respect to some convenient map of the region in which the ship is sailing. The same information is available in the form of loran tables for the convenience of navigators who desire to cross loran lines of position with celestial observations on their regular navigators chart.

The diagram of Figure 15–28 illustrates the basic principles of the determination of position by means of loran.

15–3b. Transmitting Station Functions—Loran, through the medium of radio waves, covers the main traffic lanes of the seas and oceans of the globe with electronic lines of position to aid and protect the modern navigator in his pursuit of the ancient art of celestial navigation. These electronic lines stem from the loran transmitting station, the heart of the system.

Because loran is concerned with the measurement of radio signals from two different sources, loran stations operate in pairs. The function of each station of a loran pair is somewhat different from that of its companion station and each is given a designation which is descriptive of the role which it performs, namely, "master" station and "slave" station.

The "master" starts the cycle of transmission by sending out a pulse of radio energy which is radiated in all directions including that of both the navigator and the "slave" station. After traveling over the distance between the two transmitting stations, which is known as the "baseline," the pulse transmitted by the "master" arrives at the "slave." This signal is received by means of the loran equipment of the "slave" station and the time of its arrival is used by the "slave" as a reference for the transmission of its own signal.

After the "slave" transmits its pulse, the entire cycle is repeated again and again.

Thus the "master" station sets the pace and the "slave," by following, completes the loran transmitting cycle. This is shown diagrammatically in Figure 15–29.

By this simple process, a pair of loran stations send out their guiding signals to the hundreds or thousands of navigators who may be within the area of their service which, in most cases, is well over 1 million square miles!

15–3c. Control of Loran Transmissions—Since the value of the loran system is equal only to the accuracy of timing of the signals transmitted, every precaution is taken to safeguard the functioning of the system. This is effective to such an extent that the navigator may feel certain that the loran data which he obtains is correct. This fact has been proven by the acid test of completely successful loran operation under the severe conditions imposed by the war.

The nature of loran transmitting station equipment makes it necessary for the loran transmitting station operator to observe the signals of both stations continuously during transmission. As a consequence, the man on watch at either station of a pair is in a position to "double check" for the existence of any fault that might occur in the signal of either station.

As an additional precaution to insure proper transmissions, independent monitor stations have been established at strategically located points with respect to the transmitting stations. The monitor stations maintain a continuous watch over the accuracy of the loran signals transmitted, assuring that the signals are synchronized within established limits of accuracy and take appropriate action in the case of any discrepancy.

Loran transmissions can be momentarily at fault due to many possible causes such as electrical failure of a part of the equipment or operating error in manipulating controls. Even though these troubles may be minor and of relatively short duration, it is absolutely essential that the navigator be acquainted with the failure instantly and positively. In order

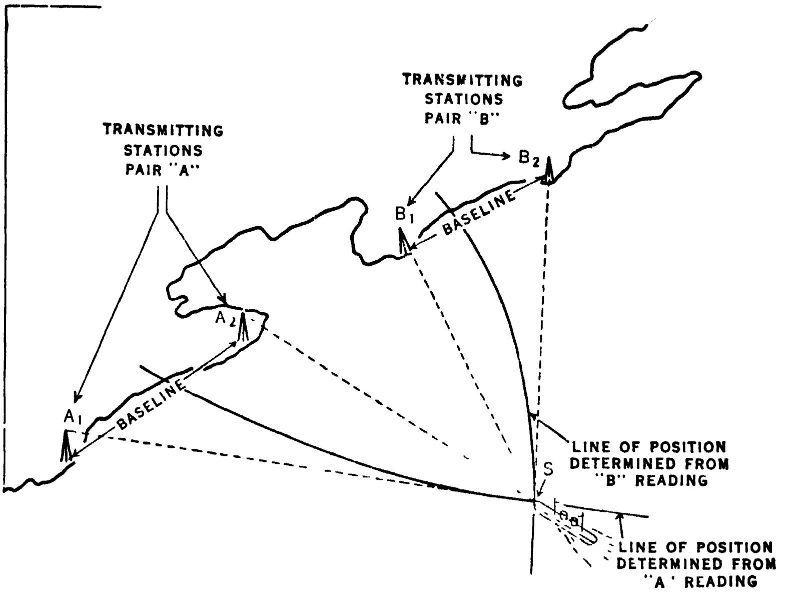

TRANSMITTING STATIONS PAIR "B"
TRANSMITTING STATIONS PAIR "A"
B_2
B_1
BASELINE
A_2
A_1
BASELINE
LINE OF POSITION DETERMINED FROM "B" READING
S
LINE OF POSITION DETERMINED FROM "A" READING

FIG. 15–28. Navigator aboard loran-equipped ship at S establishes "fix" by determining two lines of position, A and B, by loran measurements. Line of position A is found by measuring the time difference between signals received from transmitting stations A_1 and A_2. Line of position B is found by measuring the time difference between signals received from transmitting stations B_1 and B_2. The navigators fix is established at the point of intersection of the two lines of position. The latitude and longitude of the navigator's position is determined from the loran data by using the loran charts or loran tables.

to do this, a blinker device is switched in at either of the two stations. "Blinking" produces a characteristic movement of the transmitted signals, which is easily recognizable and serves to warn the navigator that the signals are not to be used for navigational purposes until the blinking ceases.

In case the failure is sufficiently serious to prevent transmission entirely, from one of the paired stations, it would not be possible for the navigator to misinterpret the loran signals since the presence of only one of the expected signals on the air would preclude making any time difference measurements at all from that particular pair. Other pairs would not be effected.

Because of the fundamental checks which are vigilantly maintained on the operating loran signals, the navigator at sea or in the air is assured that any transmissions which he receives, with the exception of "blinking" signals, are accurate, reliable electrical guideposts marking the electronic lines of positions of this modern long-range navigational aid.

15–3d. Transmitting Station Equipment—In order to send out a succession of reliable loran signals to aid navigators at sea in determining their position, the transmitting station has two fundamental responsibilities. The first of these is the generation of radio impulses of the proper frequency, power, and duration. The second is the timing of these radio impulses at the correct intervals and with the required degree of precision. The two major units of transmitting station equipment fulfill these responsibilities, as their names indicate, since they are the loran transmitter and the loran timer.

The loran transmitter is a pulse type of equipment of a special design developed specifically for loran application. The radio frequency pulses which are generated by the equipment contain a great deal of electrical energy and are as powerful, although of short duration, as the largest commercial broadcasting stations' transmissions. The loran transmitter functions in such a manner that a single pulse of radio energy is sent out each time the transmitter receives an electrical timing impulse. The timing impulse is known as a "trigger" pulse and serves to turn on the transmitter for the duration of the pulse.

The loran timer is the fundamental unit of equipment on which the accuracy of the loran system depends. The timer is made up of the following basic components which serve the purposes indicated:

(a) *Radio receiver.* The receiver permits the reception of loran signals from the distant station and also those transmitted by the local station.

(b) *Indicator.* Based upon the function of the cathode ray tube which permits the operator to see electrical impulses, the indicator permits visual inspection of the signals themselves and other basic functions of the equipment.

(c) *Oscillator and timing circuits.* The complex and precise timing functions stem from a crystal

Step I. Navigator aboard ship at "N" is within range of stations "M" and "S" and is about to receive loran signals.

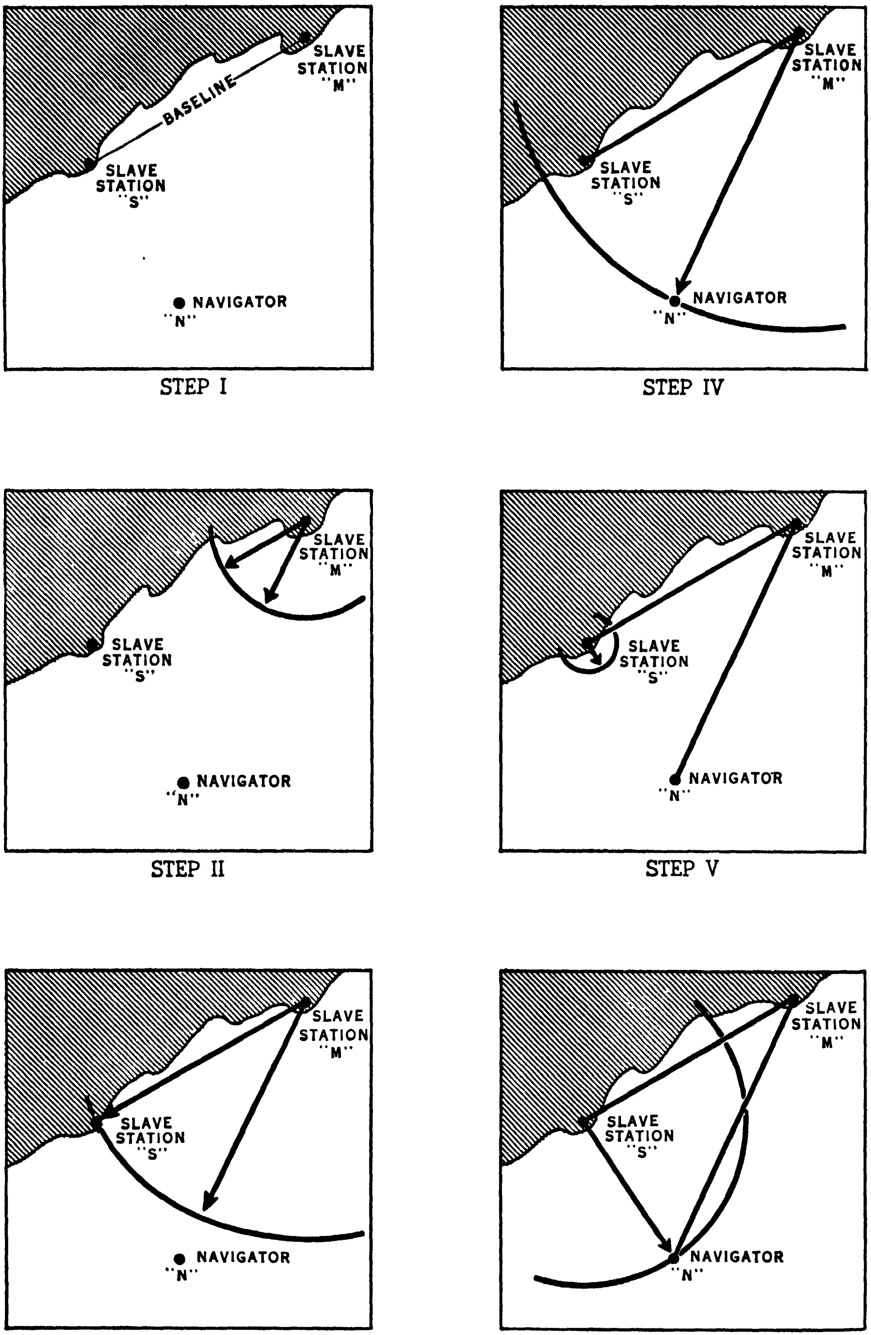
Step II. Loran transmission cycle is begun by "master" station. Pulse is radiated in all directions and travels toward both "slave" station and navigator.

Step III. Pulse transmitted by "master" station arrives at "slave" but has not yet reached the navigator.

Step IV. Pulse from "master" station arrives at position of navigator. "Slave" station has already received "master" pulse and is waiting for proper amount of time to elapse before transmitting to assure correct synchronization with "master."

Step V. After waiting for the proper amount of time to assure correct synchronization the "slave" transmits its pulse. The navigator has already received the pulse from the "master" station.

Step VI. "Slave" pulse arrives at navigator's position. Since navigator has already received the signal from the "master" station loran reading is taken by measuring the time elapsed between the arrival of the "master" and "slave" pulses. After both signals have traveled throughout their effective range, the cycle is repeated.



STEP I STEP IV

STEP II STEP V

STEP III STEP VI

Fig. 15–29. Sequence of operation of loran transmitting stations.

controlled oscillator of the highest laboratory standards. The timing circuits permit the measurement of the time interval between the signals received and furnish the necessary trigger pulses for operating the loran transmitter and similar timing pulses for other secondary station functions.

Some idea of the high degree of precision of the loran timer equipments may be illustrated by the fact that a pocket watch of comparable accuracy would run for a period of over 9½ years before it would lose or gain a single second of time.

A third item of equipment which is of fundamental importance in a transmitting station is the loran switchgear. This is constructed as a separate physical unit and contains the necessary switching to permit the operator to place different units of the station equipment in use by properly connecting them to the other units. The switchgear chassis also houses the "attenuator" unit, an electronic switch which effectively disconnects the receiver unit each time the local transmitter sends out a signal. It is necessary to do this to prevent the receiver from being damaged by the strong signal that is generated in the vicinity of the station's own transmitting antenna. During the interval when the local transmitter is not sending out a signal, the attenuator effectively reconnects the receiver to permit the operator to receive the signal from the distant station.

In order to provide reliable loran service even in the case of minor failures of equipment it is the established practice in designing loran stations to provide duplicate units of all of the major items. In this manner an equipment failure causes only a momentary pause in the service, since the stand-by equipment can usually be placed in service in less than a minute's time.

15-3e. Equipment Used by the Navigator—Loran equipment used by the navigator on shipboard or aircraft at sea in the determination of his position, is known as a receiver-indicator. The receiver performs the functions of an ordinary radio receiver but delivers its output to a visual indicator rather than to a loudspeaker and is designed for the reception of pulsed signals rather than ordinary radio signals. The indicator is essentially an electronic stop-watch capable of measuring, in microseconds, the difference in times of arrival of pulse signals from the two stations of a pair. In the indicator, horizontal traces on the screen of a cathode ray oscilloscope form the equivalent of the dial of a watch. A vibrating quartz crystal is the balance wheel, and electrical circuits known as "dividers" or "counters" take the place of gear wheels.

Installation of the receiving equipment is quite simple and can be performed in a few hours time. Actually, installation merely requires simple mechanical mounting of the equipment to the deck or bulkhead, erection of an ordinary radio receiving type vertical antenna, and plugging in the power cord to the local electrical power source.

15-3f. Operating Range and Accuracy—Three fundamental characteristics of loran are of particular importance to navigators using the system. These qualities are the following:

(1) Practicability of loran operation over longer distances than is possible with older types of radio navigational aids.

(2) High order of positional accuracy attained.

(3) Reliability of loran under all kinds of weather conditions.

Vessels and aircraft at sea may determine their position by means of loran both day and night when they are within 750 nautical miles of the transmitting stations. This is based on the reception of "ground waves" which travel on the surface of the earth and which are the most stable type of radio waves. At night, however, "sky waves" are received which are radio waves that travel outward from the transmitter until they are reflected from a region of the upper atmosphere known as the "ionosphere" and reach the navigator after reflection (Figure 15-30). The use of "sky waves" extends the range of loran service at night up to a distance of 1400 nautical miles from the transmitting stations. However, the positional data obtained by using sky wave loran signals is somewhat less accurate than the information determined through the use of ground waves, but is, nevertheless, still at high order

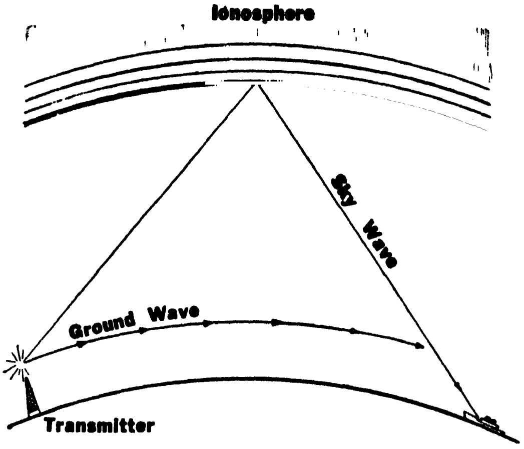


Fig. 15-30. Paths of ground wave and sky wave transmission.

One of the surprising facts about loran is that in a matter of 2 to 3 minutes time, a navigator at sea can determine his position with an accuracy comparable to that obtained from good celestial observations which require considerably longer to make and which entail somewhat laborious mathematical computations to interpret.

The accuracy of loran fixes varies considerably, depending on the relative position of the navigator and the transmitting stations, the angle at which the loran lines of position intersect and several other factors. A very rough rule of thumb has been stated to be that a loran line of position has an accuracy of better than 1 percent of the distance of the navigator from the stations; thus a navigator 1000 miles away from the stations would expect the line of position to be well within 10 miles of the proper position. As the stations are approached, the accuracy increases greatly, and along the imaginary line between the two stations, or base line, a line of position may have an accuracy of the order of several hundred feet. This feature has particular practical value since the physical arrangement of loran stations is such that a navigator making a

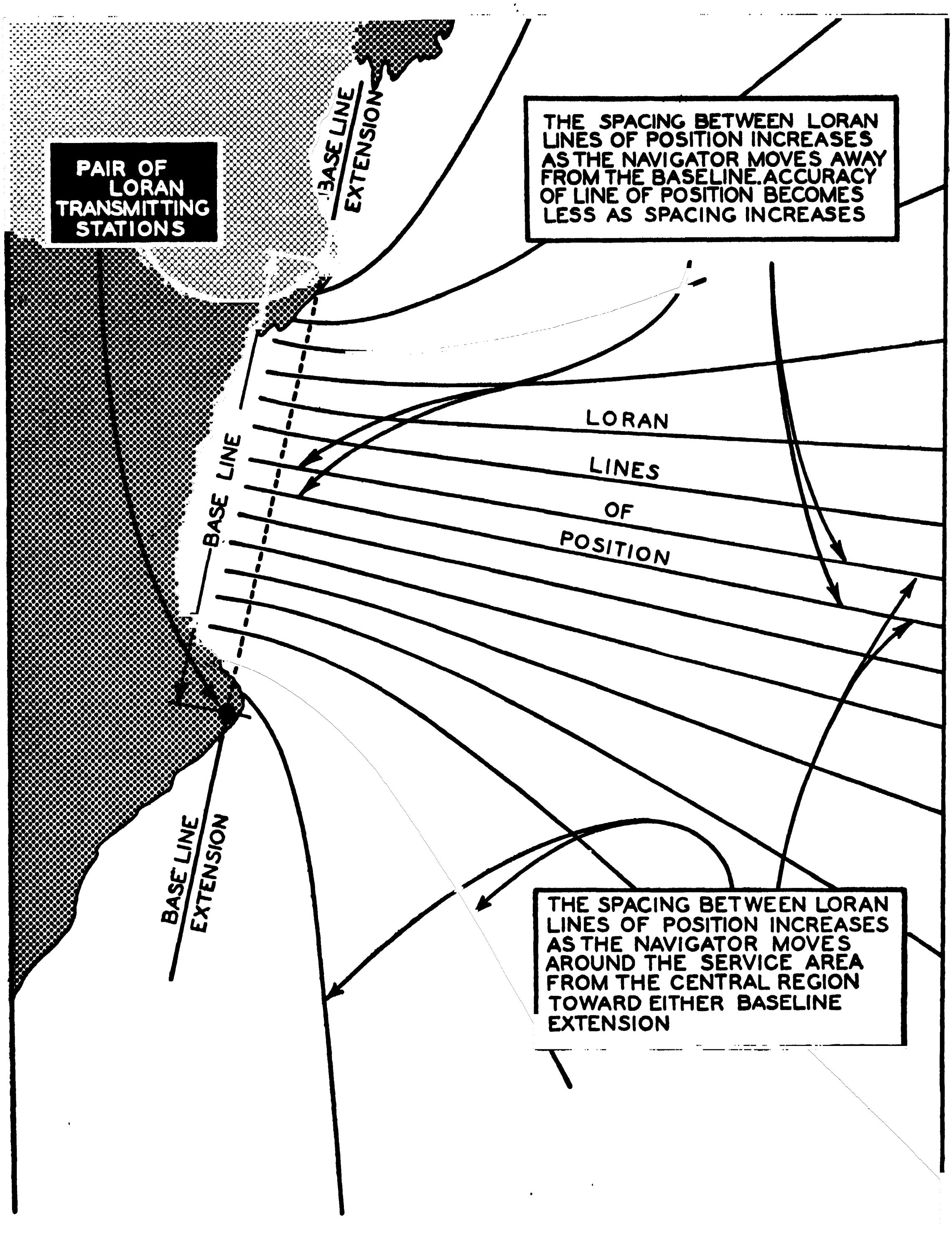

PAIR OF LORAN TRANSMITTING STATIONS
BASE LINE EXTENSION
THE SPACING BETWEEN LORAN LINES OF POSITION INCREASES AS THE NAVIGATOR MOVES AWAY FROM THE BASELINE. ACCURACY OF LINE OF POSITION BECOMES LESS AS SPACING INCREASES
LORAN LINES OF POSITION
BASE LINE
BASE LINE EXTENSION
THE SPACING BETWEEN LORAN LINES OF POSITION INCREASES AS THE NAVIGATOR MOVES AROUND THE SERVICE AREA FROM THE CENTRAL REGION TOWARD EITHER BASELINE EXTENSION

FIG. 15-31. Loran lines of position.

landfall will usually approach the shore in this highly accurate area of loran service. Figure 15-31 shows the pattern that a family of loran lines of position make with respect to their transmitting stations and points out the regions of accuracy. Figure 15-32 shows a vessel approaching a harbor along a line of position.

Another important feature of loran is the reliability of the signals and the consequent removal of doubt as to the dependability of loran fixes.

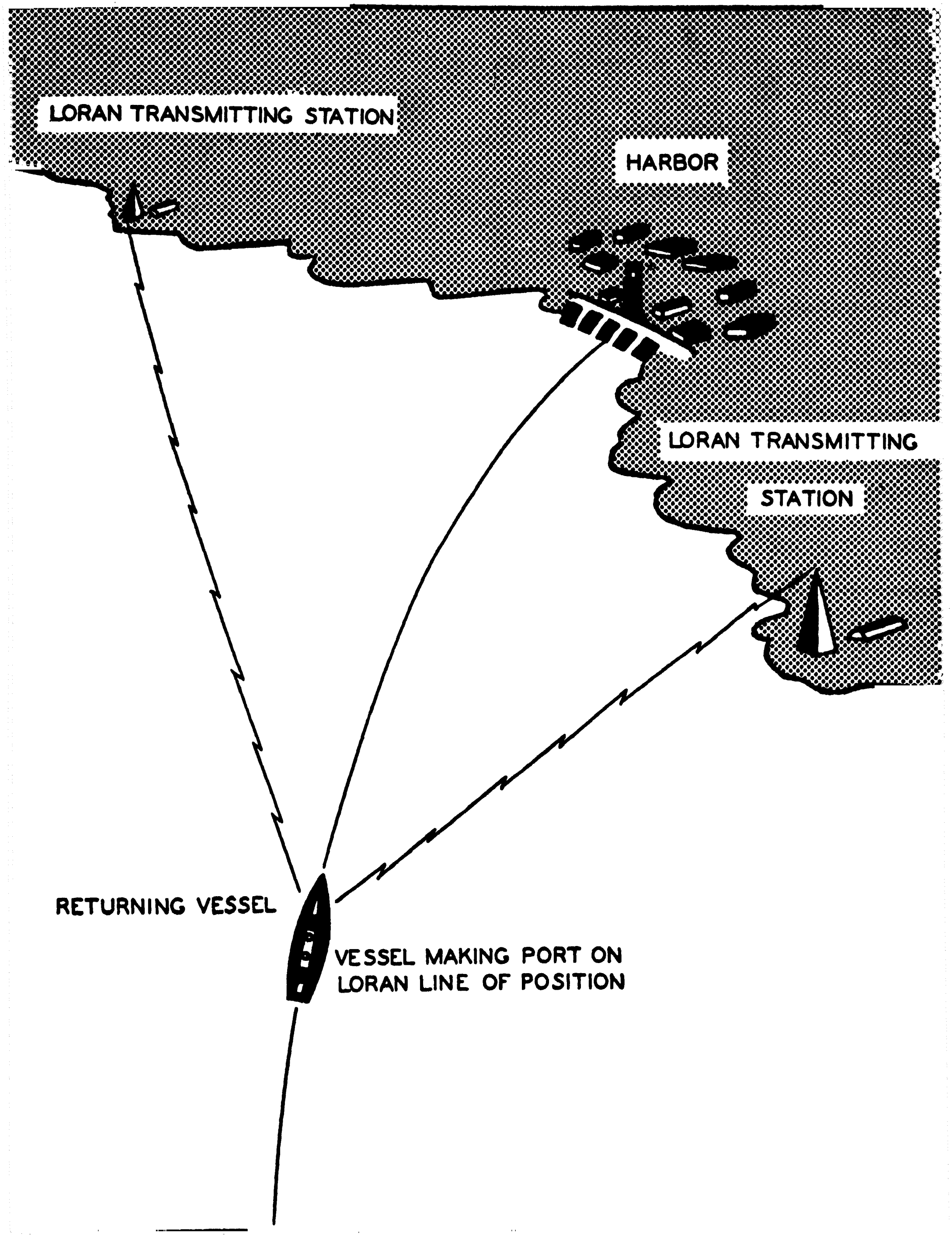

LORAN TRANSMITTING STATION
HARBOR
LORAN TRANSMITTING STATION
RETURNING VESSEL
VESSEL MAKING PORT ON LORAN LINE OF POSITION

Fig. 15-32. Vessel approaching harbor along loran line of position.

Loran signals can be received under all ordinary conditions of storms, gales, and other severe weather. This is possible because the ordinary electrical interferences that accompany these conditions obscure the loran signal for only a few seconds at a time and the navigator need only wait for a few moments to obtain usable data. The greatest safeguard in this respect is the fact that loran signals are always accurate when they are received at all. In the case of some unusual interference that might completely block the loran signals, no data could be obtained at all. There is no "in between" condition in the use of loran for navigation and as a consequence, the navigator may always feel assured that any loran data that he obtains will be of customary accuracy and dependability. For these reasons loran is an especially valuable asset to navigation during bad weather.

15–3g. Loran System Description

1. *Loran:* A long range aid to navigation for the determination of position based upon the difference in times of arrival at the navigator's position of radio signals transmitted from two fixed loran transmitting stations.

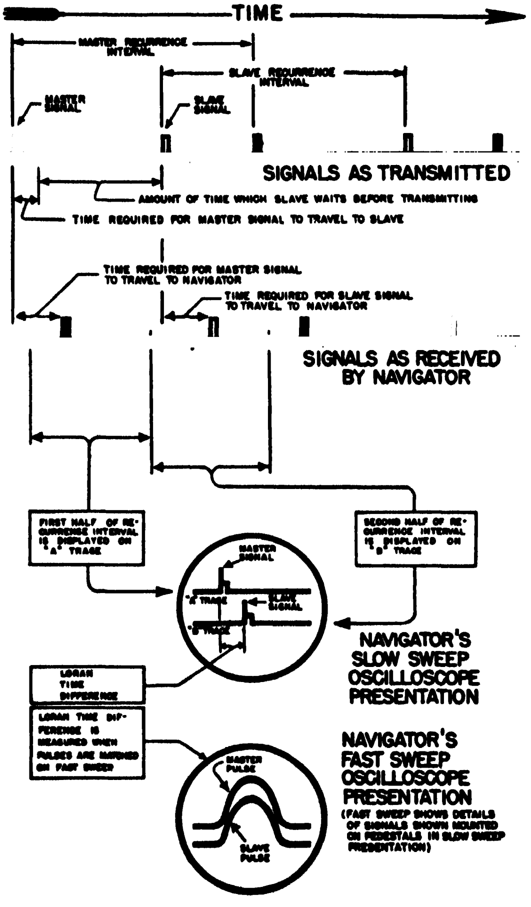

TIME
MASTER RECURRENCE INTERVAL
SLAVE RECURRENCE INTERVAL
MASTER SIGNAL
SLAVE SIGNAL
SIGNALS AS TRANSMITTED
AMOUNT OF TIME WHICH SLAVE WAITS BEFORE TRANSMITTING
TIME REQUIRED FOR MASTER SIGNAL TO TRAVEL TO SLAVE
TIME REQUIRED FOR MASTER SIGNAL TO TRAVEL TO NAVIGATOR
TIME REQUIRED FOR SLAVE SIGNAL TO TRAVEL TO NAVIGATOR
SIGNALS AS RECEIVED BY NAVIGATOR
FIRST HALF OF RECURRENCE INTERVAL IS DISPLAYED ON "A" TRACE
SECOND HALF OF RECURRENCE INTERVAL IS DISPLAYED ON "B" TRACE
MASTER SIGNAL
"A" TRACE
SLAVE SIGNAL
"B" TRACE
LORAN TIME DIFFERENCE
NAVIGATOR'S SLOW SWEEP OSCILLOSCOPE PRESENTATION
LORAN TIME DIFFERENCE IS MEASURED WHEN PULSES ARE MATCHED ON FAST SWEEP
MASTER PULSE
SLAVE PULSE
NAVIGATOR'S FAST SWEEP OSCILLOSCOPE PRESENTATION
(FAST SWEEP SHOWS DETAILS OF SIGNALS SHOWN MOUNTED ON PEDESTALS IN SLOW SWEEP PRESENTATION)

FIG. 15–33. Loran timing sequences.

2. *Type of transmission.* Loran transmissions are "pulse" transmissions. Very short pulses of radio frequency energy are radiated at periodic intervals which are very long compared to the duration of the pulse. During the interval between successive pulses of a station, no radio signal from that station is on the air.

3. *Radio frequency:* Loran signals are transmitted at the present time on three frequency channels:

1950 kc
1850 kc
1750 kc

4. *Pulse definition:* The loran pulse signal is of approximately 80 microseconds duration and the rectified envelope has a shape similar to that of a sine wave when viewed on a loran receiver. It is customary to measure pulse width at one-half amplitude; standard width is thus considered to be 40 microseconds.

5. *Pulse repetition rates:* Loran pulses are transmitted at a number of different repetition rates. Differences in repetition rate is the means of identification of particular pairs of stations. Specific pulse repetition rates are assigned in several general categories with the particular rates of each category being only slightly at variance with a convenient rate known as the "base rate." Present "base rates" and "specific repetition or recurrence rates" are tabulated below:

BASE RATE 25 CYCLES (PULSES) PER SECOND

Specific Rate Designation	*Frequency (cps)*	*Interval (microseconds)*
0	25	40,000
1	$25\frac{1}{16}$	39,900
2	$25\frac{1}{8}$	39,800
3	$25\frac{3}{16}$	39,700
4	$25\frac{1}{4}$	39,600
5	$25\frac{5}{16}$	39,500
6	$25\frac{3}{8}$	39,400
7.	$25\frac{7}{16}$	39,300

BASE RATE $33\frac{1}{3}$ CYCLES (PULSES) PER SECOND

Specific Rate Designation	*Frequency (cps)*	*Interval (microseconds)*
0	$33\frac{1}{3}$	30,000
1.	$33\frac{4}{9}$	29,900
2.	$33\frac{5}{9}$	29,800
3.	$33\frac{2}{3}$	29,700
4.	$33\frac{7}{9}$	29,600
5.	$33\frac{8}{9}$	29,500
6.	34	29,400
7.	$34\frac{1}{9}$	29,300

New loran transmitting station equipment is capable of operation on a base rate of 20 cps to provide for future expansion of the system without requiring additional radio frequency allocations.

6. *Loran timing sequences:* (Loran timing sequences are shown graphically in Figure 15–33.) Master and slave stations are pulsed at exactly the same pulse recurrence rate. The master pulse is transmitted first and, after traveling the distance of

the base line, arrives at the slave where it is received and used as a timing reference. After waiting for a predetermined length of time which is necessary to establish correct loran synchronization, the slave station transmits its pulse. The amount of time that the slave waits, or delays, is always fixed at an amount greater than one-half of the recurrence interval, and, as a consequence, the master signal is always transmitted during the first half of the recurrence interval and the slave transmission always occurs during the second half of the interval, regardless of the navigator's position with respect to the stations The signals are received and viewed by means of a cathode ray oscilloscope using a time base equal to the recurrence interval but divided into two equal half-interval traces so placed on the scope by the sweep circuits that two half-traces appear with the first half directly above the second half. Both traces are horizontal in time sweep.

The controls of the receiving instrument are adjusted until the master signal is viewed near the beginning of the upper, or "A," trace. The slave signal will appear in its proper place on the lower trace. Measurement of the loran time difference is made by evaluating the horizontal displacement of the slave station with respect to the master in terms of time, microseconds. By this physical arrangement of the traces the half recurrence interval delay which was introduced by the slave is effectually canceled from the measurement. Loran readings thus obtained may be interpreted in conventional coordinates by the use of loran charts or tables. A fast speed time base having a duration of roughly from 100 to 300 microseconds is provided to permit visual examination of the pulse envelope itself which is necessary to establish the precise adjustment required in making a loran reading.

7. *Blinker signal:* The timers at loran transmitting stations are equipped to perform a function known as blinking. The signal is used to indicate that the transmissions should not be considered reliable during the period of blinking. In general, blinking causes the received pulse to rhythmically swing back and forth as viewed on the slow sweep, and to rhythmically appear and disappear on the fast sweep. In the few exceptions to this method, due to a difference in transmitting equipment, there is a rhythmic appearance and disappearance on both slow and fast sweeps.

15–3h. Loran Receiver

1. *Operating radio frequencies:* The radio receiver of a loran receiver-indicator is provided with four radio frequency channels and may be set for operation on any of the frequencies tabulated in the system specification. In operation, receiver tuning is fixed and a four-position switch provides simple means of changing channels.

2. *Receiver sensitivity:* The receiver has a sensitivity sufficiently high that a signal of approximately 10 microvolts delivered by the antenna to the receiver input will result in full scope deflection of the cathode ray indicator. Receiver and indicator form an integrated unit and are not intended to function separately.

3. *Bandwidth:* Early designs incorporated a total bandwidth of the order of 80 kilocycles at 6 db down. Current trends are toward considerable reduction and total bandwidths of 40 kilocycles or less at the same decibel limitation are contemplated.

4. *Differential gain amplifier:* The receiver incorporates a differential amplifier which operates in synchronism with the incoming signal recurrence frequency to permit amplification of each of the two signals received at different ratios. This feature permits presentation to the cathode ray indicator of signals of equal amplitude. Sufficient range of operation is provided to permit accommodation of incoming signals having a ratio of strengths as high as 500 to 1. Earlier equipments had an operating limit of roughly 100 to 1.

15–3i. Loran Indicator

1. *Functional purpose:* The indicator unit contains the necessary circuits to perform all of the timing functions of the equipment with the required precision. It contains the sweep generators and the cathode ray tube for presentation of the signals received.

2. *Master oscillator:* The basic timing medium of the equipment is a precision, crystal controlled, master oscillator. The oscillator possesses a high order of short time stability in the order of a few parts in 10 million. Manual means of adjustment is provided to vary the frequency over a range of more than 200 parts in a million. This adjustment permits cycling the oscillator until the timing of the receiver-indicator is in exact step with the recurring pulses received from the transmitting stations.

3. *Timing markers:* Through the medium of its timing circuits, the indicator provides a sequence of precise timing markers spaced at convenient intervals to facilitate measurement of time sequences with a basic accuracy in the order of plus or minus 1 microsecond.

4. *Time Base:* The sweep generators provide a slow sweep as outlined in the system specification which covers the entire recurrence interval by means of a divided trace. A fast sweep lasting in the order of 200 microseconds or less is provided and by means of delay controls may be positioned to examine the particular sections of the time base at which a signal appears. For convenience in identification and for purposes of triggering and delay measurement a pedestal or raised rectangular pulse appears on the slow sweep presentation in the portion covered by the fast sweep. Timing arrangements are made to permit the fast sweep gen-

erator to fire at a predetermined point on both the upper and lower traces.

5. *Matching pulses:* To measure loran time differences, the time base is cycled with respect to the transmissions until the master and slave signals appear at convenient points on the upper and lower traces, respectively, with adjustment being made such that the fast sweep generator fires precisely in the region of both signals. The signals are examined on the scope operating on fast sweep and a fine adjustment is made until the pulses are superimposed or matched with respect to time. Time difference measurements are made by means of timing markers.

6. *Equipment power requirements:* Loran receiver-indicators for shipboard installation are designed to operate on 115 volt (nominal) 60 cycles, single phase, alternating current, are rated at from 200 to 300 watts.

Aircraft equipments are made to operate on voltages of from 80 to 115, single phase, alternating current, and on frequencies from 360 to 2460 cycles. Equipments are rated at less than 200 watts.

7. *Receiving antenna:* Receiving antenna installation is simple since only a vertical wire is required. A length of 50 to 60 feet is considered desirable although satisfactory operation is experienced when physical conditions require considerable decrease in the effective antenna length.

8. *Method of obtaining loran readings:* The majority of loran receiver-indicator equipment now in use was that developed and manufactured during the war. This equipment requires that time difference determinations be made by matching master and slave pulses and then by switching to additional scope selection positions and by reference to a set of markers, count the divisions and thereby arrive at the reading. Receiver-indicators now being manufactured and installed which incorporate direct reading counters, so that once the pulses are matched, all that is necessary to determine the time difference reading is to refer to a counter device which shows directly the proper numerical reading. Equipments under development for future use contemplate automatic matching of pulses as well as the direct reading counters.

15–4. Radio Direction Finders—Radio direction finding is an important aid to navigation and is made possible because radio waves, under normal conditions, propagate between two points by means of a great circle route. This enables a ship or aircraft to determine the direction from which radio waves from a distant transmitter are arriving, and if bearings are taken on two or more transmitting stations of known location, the ship or aircraft can ascertain its position. In a similar manner, the location of a radio transmitter can be determined if bearings are taken by two or more suitably located direction finder receiving stations.

The loop type radio compass,[3] or direction finder,[3] was principally developed in this country by the U. S. Navy and successfully introduced as an aid to navigation. Since its introduction and increasing use, the United States Coast Guard has established automatic radio beacons on light vessels and at lighthouses in the vicinity of harbor entrances and places dangerous to navigation, the exact locations of which are clearly shown on all navigation charts. These stations send out characteristic radio signals, thus enabling a vessel fitted with a radio compass to take bearings as often as desired.

15–4a. Fundamental Principles—It has long been known that an antenna consisting of a loop or closed coil has directional properties. Consider the loop of wire in Figure 15–34a as being supported vertically with its edge pointing in the direction of a radio transmitting station.

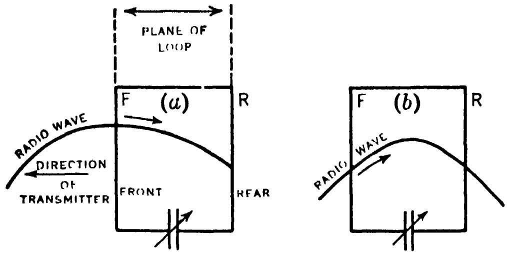


Fig. 15–34. Passing radio wave inducing signal in loop antenna.

The wave front of a signal from the transmitter will pass through the side of the loop marked F a small fraction of time before it passes through the side marked R. This results in voltages of like phase being induced in each side of the loop. These induced voltages flow through the loop circuit in opposite directions and tend to oppose each other. However, it will be noted (Figure 15–34a) the F side of the loop is being cut by a point on the r-f cycle of the passing wave with greater amplitude than the point on the r-f cycle cutting the R side, therefore, at the instant shown, the induced voltage in the F side is of greater strength. A voltage will therefore be developed across the loop terminals proportional to the difference between these two voltages and an r-f current will flow in the loop circuit. When the loop circuit is resonant to the frequency of the incoming wave, a maximum voltage will be developed across the loop terminals.

As the radio wave advances, there will be an instant (Figure 15–34b) when equal voltages will be induced in both the F and the R sides of the loop. At this instant, the induced voltages in each side of the loop will completely cancel each other and the voltage across the terminals of the loop becomes zero. However, as the radio wave continues to advance, the R side of the loop will now have a greater voltage induced in it than the F side and current will again flow in the loop circuit, this time in the opposite direction. The above cycle of events is repeated as the successive cycles of the passing radio wave cut through the loop. It will be noted that the points of maximum voltage in the passing wave correspond to points of minimum loop voltage, therefore the phase of the voltage across the loop terminals is 90° out of phase with the voltage of the passing radio wave.

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[3] The terms "direction finder" and "radio compass" are used synonymously in this chapter.

Now consider the loop turned 90° so as to be at right angles to the arriving wave front. The passing wave will in this case cut both the F and the R sides of the loop at the same instant. This results in voltages equal in amplitude and phase being induced in the loop, however as these voltages flow through the loop in opposite directions, the result is complete cancellation and no r-f current will flow through the loop circuit.

If the terminals of the loop are connected to a suitable radio-frequency amplifier and detector, the signals from the transmitting station will be heard with the greatest strength when the loop points in the direction of the transmitting station, that is, when the plane of the loop lies in the direction of the source of transmission. As the loop is rotated from this position of maximum signal strength, the signal will gradually reduce in strength and when the plane of the loop reaches a position at right angles to the source of transmission, the signal intensity will be zero. If the rotation of the loop is continued, the signal will gradually reappear, reaching a maximum strength when the plane of the loop again lies in the direction of the source of transmission. Referring again to Figure 15-34, the R side of the loop has now become the F side, and vice versa. If the signal intensity is measured during the above rotation, it will be found that the signal strength varies in accordance with a figure-eight characteristic as shown in Figure 15-35, directions A and B corresponding to directions of maximum loop sensitivity.

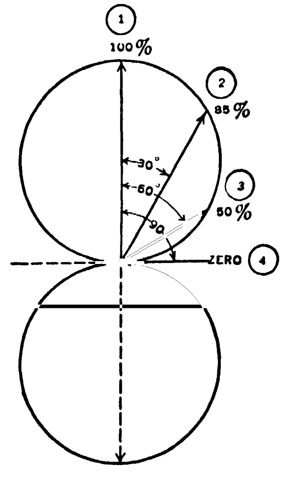


Fig. 15-35. Ideal figure-eight directional characteristic of well-balanced loop antenna.

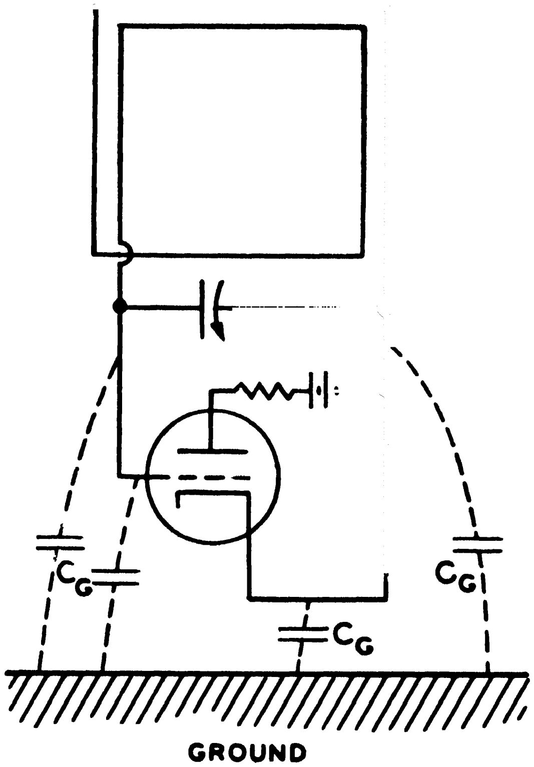


Fig. 15-36. Loop antenna circuit showing unbalance-to-ground brought about by connection to vacuum tube circuit.

15-4b. Capacitance of Loop Circuit to Ground—An important factor that must be considered in the application of the loop antenna to direction finding is the distortion of the desired figure-eight response characteristic if the loop is not electrically balanced with respect to ground. Under these circumstances of poor balance, the loop acts to a certain extent as a conventional antenna; this effect, known as "antenna effect," tending to destroy the desired figure-eight response. In addition, the associated amplifier and detector circuits employed with the loop antenna are often unsymmetrical with respect to earth and unless the loop is properly coupled to these circuits, the ideal figure-eight characteristic may also be distorted or completely destroyed.

Figure 15-36 shows how such an unbalance-to-ground may be brought about. In the circuit shown, the loop terminals are connected to the grid and cathode elements of a vacuum tube amplifier or detector. The dotted lines C_g represent capacitance between the loop and other apparatus to ground. Because of the electrically unsymmetrical relation of the loop to ground, an appreciable current will be set up in the loop circuit by the incoming wave acting through the earth capacitances C_g. A potential produced by this current across the loop tuning capacitor causes a signal to be delivered to the grid of the vacuum tube even when the loop is in a "null." The ideal figure-eight loop characteristic is therefore distorted by these effects, the degree of distortion depending upon their relative magnitudes. A typical distorted loop characteristic which results is shown in Figure 15–37. As can be seen, the position of minimum signal intensity is no longer at right angles to the plane of the loop, nor does it coincide with the axis of the loop as in the ideal case.

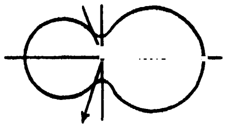


Fig. 15–37. Distorted loop characteristic due to "antenna effect."

The solution of this problem depends upon obtaining exact electrical symmetry of the loop system, including the associated vacuum tube circuits, with respect to earth. One method of accomplishing this is to employ a push-pull vacuum tube arrangement. Another method, employing inductive coupling and, in addition, small condensers to balance out the so-called antenna effect, is shown in Figure 15–38.

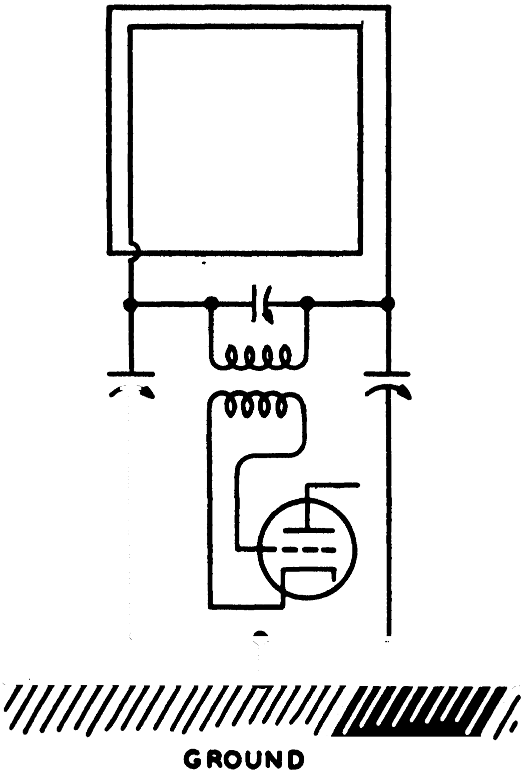


Fig. 15–38. Method of coupling loop to eliminate unbalance-to-ground.

15–4c. Determination of Sense—As has already been explained, the loop antenna, when properly balanced with respect to ground, will give a critical null response thereby indicating the line of direction of the source of radio transmission. Inasmuch as the signal null, rather than the signal maximum, is customarily used in obtaining bearings because it is more sharply defined and therefore more accurate, the actual direction of the transmission is at right angles (90° displaced) to the indicated point of zero signal. However, a 180° uncertainty exists as to the actual direction of the source of transmission as there are two points of signal null which are obtained as the loop is rotated 360°. When taking bearings on a station the general direction of which is known, this 180° ambiguity is not important as the correct bearing is easily recognized. The occasion often arises, however, when the true direction of the transmitting station must be known as, for example, in locating and proceeding to the aid of a ship in distress when no information of the actual position of the ship exists.

The true direction or "sense" of a radio transmission is obtained by employing a small, non-directional, vertical receiving antenna in conjunction with the loop antenna. In effect, this antenna when connected, tends to exaggerate the antenna effect, resulting in a cardioid receiving pattern.

15–4d. The Cardioid Pattern—The loop-type direction finder produces two signal nulls because of the inherent figure-eight directional characteristic of the loop-type of signal collector. This characteristic may be expressed mathematically by

$$E_L = E_m \cos \theta \qquad (1)$$

where E_L is the output voltage of the loop which produces the voltage E_m when its plane is parallel to the direction of arrival of the signal and θ is the angle between the plane of the loop and the line of propagation of the signal. Thus for θ equal to 90° or 270° cos θ is zero and the loop output voltage goes through two nulls in signal.

On the other hand the output voltage of a vertical signal collector is independent of the direction of arrival of the signal and mathematically may be expressed by

$$E_A = Ke \qquad (2)$$

where E_A is the antenna output voltage, e is the field strength intensity of the signal and K is a constant whose value is determined by the physical dimensions of the antenna.

By combining the output voltages of a vertical antenna and a loop signal collector in one receiver the directional field pattern is unlike either signal collector. Adding equations (1) and (2) we obtain

$$E_L\ E_A = E_m \cos \theta\ Ke \qquad (3)$$

If the amplitude of the vertical antenna voltage is made equal to E_m and if proper phasing exists then equation (3) becomes

$$E_L = E_m \; (1 \cos \theta) \qquad (4)$$

and will be recognized as that corresponding to a cardioid pattern having a single maximum when θ is 270°. The advantage of being able to obtain a cardioid pattern lies in the fact that it provides a means of determining the direction of arrival of the signal and hence is a valuable adjunct to the loop direction finder since it provides a means for getting the "sense" or direction of an incoming signal.

One of the several practical ways of obtaining a cardioid field pattern (Figure 15–39) with a "sense" antenna is to apply the vertical antenna to the grid of an amplifier tube whose output circuit is coupled to the plate circuit of the loop voltage amplifier.

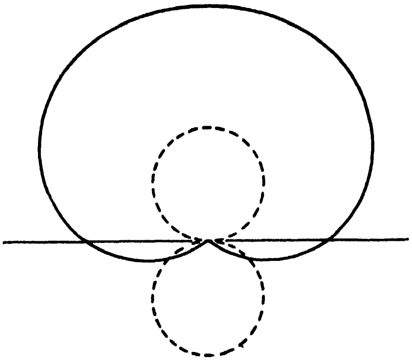


FIG. 15–39. Cardioid pattern produced when voltages from vertical and loop antennas are equal in amplitude.

By providing a gain control on the sense antenna amplifier, means are available for adjusting the amplitude of the antenna voltage so as to equal that obtained from the loop signal collector. In actual operation the sense antenna is grounded by means of a switch and the loop is oriented to obtain the usual two nulls. The loop is then rotated 90° from one of the nulls and its plane therefore lies very nearly in a line parallel to the direction of arrival of the signal. Having made careful note of the signal intensity, the loop amplifier gain is reduced to a minimum, the sense antenna is connected to its amplifier and its gain adjusted to give the same receiver output signal as was previously obtained on the loop. The loop amplifier gain is then advanced to its previous position and if the receiver output signal decreases as the loop gain control is advanced the adjustments are proceeding satisfactorily and the gain control should be advanced until the signal output reaches a minimum. Slight readjustments to the loop tuning may be required to obtain a good signal minimum to take care of proper phasing of loop and sense antenna voltages. On the other hand if the output signal increases as the loop gain is advanced from its minimum position it is an indication that the wrong loop signal maximum has been selected and the loop must therefore be displaced by 180° before further adjustments are made. The adjustments corresponding to the single cardioid null are usually carried out to indicate "sense" of the incoming signal because the single maximum of the cardioid pattern is broad and hence too insensitive for precise determination.

15–4e. Wave Front Distortion—When a direction finder is installed on shipboard, there are certain disturbing effects due to the ship's equipment, the most serious of which are due to currents induced in the direction finder by wires forming closed circuits, stays, whistle cords and the like which have a natural wave length considerably less than the working wave length. These currents are in phase opposition to the currents induced by the direct signal and therefore have the effect of decreasing the apparent sensitivity of the direction finder. Since the masts, funnels, stays, etc., lie in various directions from the direction finder, they also have the effect of shifting the apparent direction of the arrival of the signal. This latter effect is more prominent when the wave is approaching from approximately 45° from the ship's center line. In the fore-and-aft direction and directly abeam, the error is at a minimum.

Currents induced in the direction finder by masts, grounded stays, and any metal objects which can act as a vertical antenna and which have a natural wave length considerably less than the working wave length, are 90° out of phase with the current due to the signal. Therefore, no value of signal current can be obtained to cancel these antenna currents as the vectorial addition always makes the resultant greater than either component. The effect apparent to the observer is the broadening of the minima when taking bearings.

In order to compensate for the apparent shift in direction of signal and adjustment to obtain a sharp minimum signal at all angles, it becomes necessary to calibrate the direction finder. Calibration is done by taking simultaneous sight and radio bearings on a radio transmitter. After calibration, a deviation or correction curve is plotted and applied to an automatic compensator which makes the instrument direct reading and eliminates the necessity of applying a correction to the bearings.

15–4f. Proceeding with Calibration—Since the received wave is distorted or bent by the metal objects on the vessel, it becomes necessary to place such objects in a permanent condition, i.e., either insulated or grounded. The latter method is most practical as it is easiest and least expensive. However, this often cannot be done to the whistle cord, fore-and-aft stays, or other stays that form a closed loop around the direction finder loop. Therefore these are usually broken up into small lengths by insulators so that each length has a fundamental wave length lower than that of the range of the direction finder receiver.

A direction finder is usually equipped with two scale pointers. One is mounted under the compensating cover and is known as the upper scale. This indicates the actual position of the loop. The other is at the lower end of the extension shaft and indicates the true bearing after compensation is completed. During calibration, only the upper scale is used and it is adjusted so the scale reads zero when the plane of the loop is 90° from the lubber line and the glass indicator reads on the lubber line.

Radio and sight bearings are taken as near to 10° apart as possible and each bearing recorded and numbered as follows:

Bearing Number	*Upper Scale*	*Pelorus (Sight Bearing)*	*Correction*
1	72	76½	+4½

where 72 is the position of the direction finder loop, 76½ is the correct bearing as per pelorus, + 4½ is the correction to be added to the direction finder bearing to give the true bearing.

When the loop is rotated by means of the hand wheel, the characteristic signals from a beacon station will be heard with a varying degree of loudness until the plane of the coil is at right angles to the direction of the incoming waves at which point the signals should die out entirely. This position of silence is critical and sharp and therefore indicates with great accuracy the line of direction of the source.

After the ship has been swung and the required number of bearings taken, they are recorded and a curve drawn. In practically all calibration curves there are four angles where no correction is necessary and the form of the curve resembles a sine wave. Theoretically, the curve is a sine wave for practically all cases with a given amplitude and phase angle for each installation. Considerable emphasis should be given this fact in drawing the curve from the data obtained, as it will help in judging if any of the measured points are in error.

15-4g. Compensation for Error—The compensator employed with the RMCA direction finder consists of an arm mounted at the top of the lower scale pointer shaft which has a roller fitted in the end. This roller bears on a circular band that is held semirigid by 24 screws spaced 15° apart; by screwing or unscrewing as the occasion necessitates the shape of the cam is changed which causes the roller to move outward or inward at the appropriate points, thereby changing the position of the arm which in turn rotates the lower scale to read the true bearing. These twenty-four screws are numbered from 1 to 24 inclusive and are mounted directly under the upper scale.

A record should be made of the numbers on the upper scale that are immediately over the screws. Consult the calibration curve at the point corresponding to screw number 1 and note the correction.

Screw Number	*Upper Scale*	*Correction*	*Lower Scale*
1	6	+2	8
2	21		
3	36		
4	51		

In the table above, screw number 1 is under 6 on the upper scale and 6° shows a + 2° error; 6 + 2 = 8, so when the loop is at an angle of 6° the pelorus indicates a + 2° error. It then becomes necessary to set the upper scale pointer on 6 and adjust the screw number 1 until the lower pointer reads 8 which is the pelorus or true bearing at this angle. After this is completed, move the upper scale to the figures over screw 2 and adjust this screw until the lower scale pointer reads correctly for this angle and so on until all 24 screws have been adjusted. It should be noted that a minus as well as a plus error must be compensated for, depending upon the angle of the loop for a particular reading.

While the direction finder is being operated, the antenna employed for transmission and reception is placed in a neutral position, i.e., ungrounded.

15-4h. Polarization Errors in Loop Direction Finding—The loop direction finder does not permit accurate direction finding except where the signal is vertically polarized, which is a characteristic of the ground wave of standard broadcast transmitters. Accordingly, it is necessary to resort to other types of direction finders when taking bearings on sky waves since during the process of reflection from the ionosphere an electrical change in the signal occurs resulting in the production of two signal components, one of which is said to be horizontally polarized and the other vertically polarized.

Let us examine what happens when an attempt is made to take a bearing with a loop direction finder on a signal having these characteristics; that is, when the polarization is both vertical and horizontal.

Consider the plane of a loop set at right angles to the vertical plane in which the signal is propagated. If the signals were entirely vertically polarized, each side of the loop would be cut simultaneously by the field of the wave; no difference in potential would be developed, and consequently no signal would be heard. This is the position of the loop when a null or bearing is obtained on a vertically polarized ground wave. Now if the polarization of the wave rotates as the result of its travel through the ionosphere, the electrical field is no longer in the vertical plane of travel of the signal. As a result, and due to the horizontally polarized component of the signal, the top of the loop is cut by the field of the wave before the lower half and e.m.f.'s of equal amplitude but different in phase produce a resultant voltage at the terminals of the loop. Thus a signal is heard in the position of the loop where a zero should be obtained and consequently the loop position must be shifted to obtain a minimum signal with the result that an error is introduced. When using the loop direction finder as a navigational device, extreme care must be taken to distinguish sky wave from ground wave since it is the ratio of intensity of the sky wave to the ground wave in the total received signal which determines the magnitude of the error. This effect is observed generally at night and at the close of the day during winter months on those frequencies employed for marine direction finding and is referred to as "night effect."

The presence of sky wave is made evident by fading of the signal and in the shifting of the nulls.

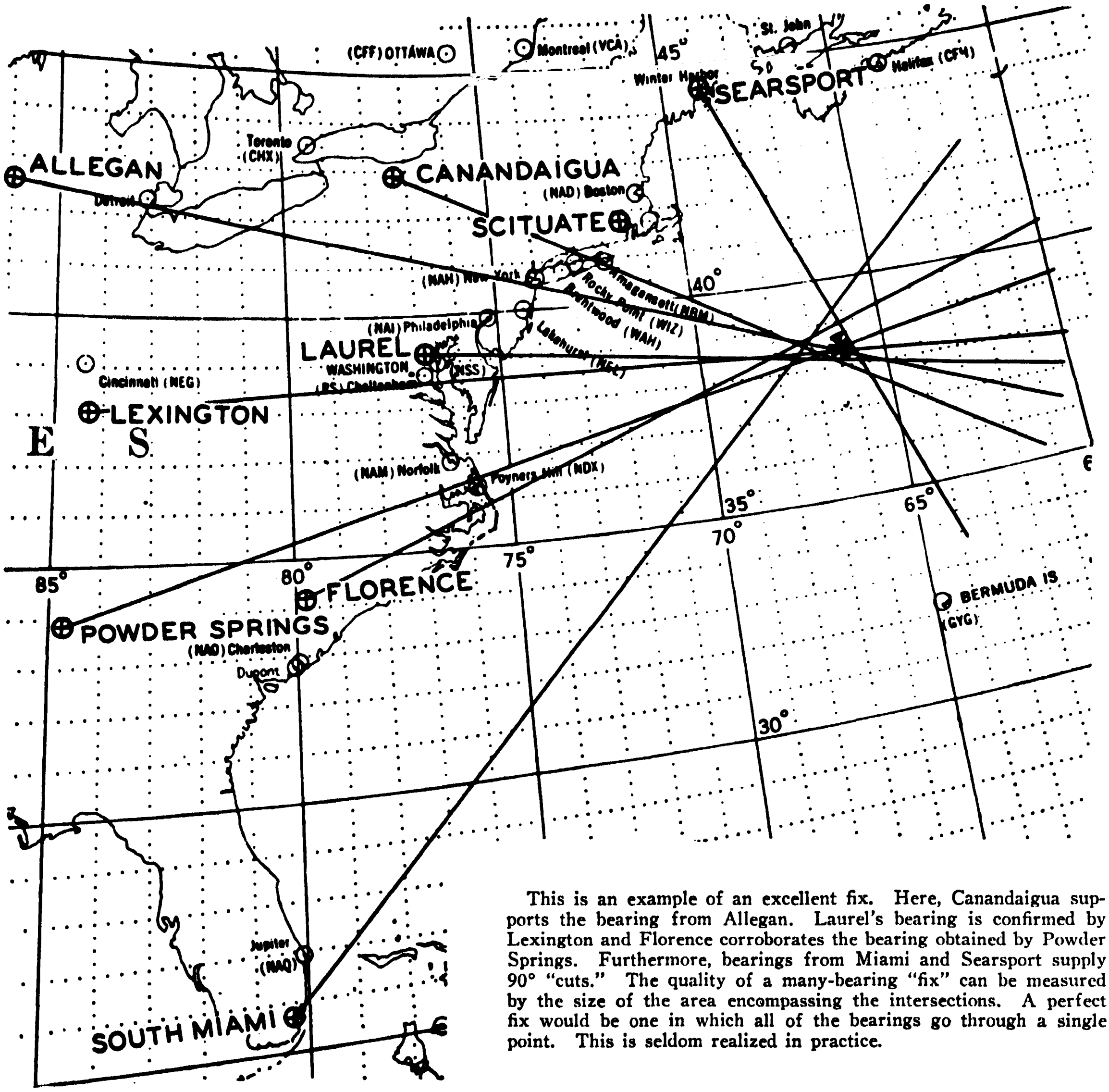
15–4i. The Adcock Direction Finder—Several systems were suggested by F. Adcock, an English engineer, having for their purpose the elimination of the polarization error in bearings. In 1919, a patent was granted Adcock for "An Improvement in Means of Determining the Direction of a Source of Electro-magnetic Radiation," which consisted of an antenna system in which the effective reception was entirely carried out by means of spaced vertical signal collectors, the e.m.f.'s in the horizontal connecting wires being either cancelled out by balancing, or avoided by suitable screening, or by other means. The photograph in Figure 15–40 shows an Adcock Direction Finder of the elevated H type developed by the Radio Intelligence Division, Engineering Department of the F.C.C. The signal collecting portion of this equipment consists of a rotating beam, approximately 20 feet long, at each end of which there are vertical metallic elements. These elements are supported at their centers and interconnected by a horizontal transmission line from the midpoint of which signal energy is taken and delivered to the radio receiver. The beam is supported at its center on a small hut mounted on top of a 20 foot tower. A pointer attached to the rotating element moves over a scale from which the radio bearings are read.

FIG. 15–40. Type B Adcock direction finder employed by the Radio Intelligence Division of the Federal Communication Commission.

The signal collectors are connected to the input of the receiver through a transposed transmission line. Maximum signal voltage is developed at the terminals of the receiver when the beam supporting the vertical signal collectors is oriented in the plane of the advancing wave. As the beam is rotated, the signal intensity decreases, and when the collectors are at right angles to the arrival of the wave, an aural null will be obtained by the operator. For this condition, the signal voltage in each vertical signal collector is the same in amplitude and alike in phase. Due to the cross connection of the transmission line, the signal voltages cancel. The pointer over the scale is offset 90 degrees from the plane of the rotating beam and the bearing on the signal is read directly from the scale.

Should the received signal contain a horizontally polarized component at the time the collectors are at right angles to the direction of the approaching wave the voltages induced in the horizontal transmission line are reduced to a small value by the transpositions in the line and in the careful electrical balancing of the output and consequently no disturbing voltages are introduced to produce a signal at the position where the null should be obtained.

However, there are other factors which influence the accuracy of the bearings including site errors, asymmetry in the signal collectors and transmission line, and lateral deviation of the signal from a great circle course. Because of these factors, absolute "pin point" fixes can seldom be obtained when endeavoring to locate a source of radio signals with Adcock direction finders. Figure 15–41 shows how bearings from several Adcock direction finders, when projected, provide a fix. It will be noted that the fix, which is in the form of a "cocked hat," embraces a triangular area. In evaluating the accuracy of the fix, bearings are weighed according to existing propagation conditions, the angle of intersection with other bearings, and the distance from the direction finder to the area of the radio signal. For example, a bearing obtained from the Miami



This is an example of an excellent fix. Here, Canandaigua supports the bearing from Allegan. Laurel's bearing is confirmed by Lexington and Florence corroborates the bearing obtained by Powder Springs. Furthermore, bearings from Miami and Searsport supply 90° "cuts." The quality of a many-bearing "fix" can be measured by the size of the area encompassing the intersections. A perfect fix would be one in which all of the bearings go through a single point. This is seldom realized in practice.

Fig. 15–41. Bearings projected from several Adcock direction finders to provide a fix on a radio transmission.

station (Figure 15–41) having a quality of plus or minus three would be given less weight than one from Searsport having a quality of plus or minus one. A high quality bearing from Miami however would be helpful in reducing the area of the cocked hat since it comes from an angle providing a good cut.

15–4j. Cathode-ray High-frequency Direction Finder—Figure 15–42 shows the vertical antenna arrangement utilized in an Adcock direction finder developed by the International Telephone and Radio Laboratories and employed in the monitoring system of the Federal Communications Commission. This apparatus is equipped with an instantaneous automatic bearing indicator of the cathode ray type which enables the operator to quickly secure a bearing even though the duration of the transmission may be only a single letter. Moreover, the system has three additional advantages:

(1) It permits the quality of the bearing to be obtained.

(2) It permits determination of the sense or direction of the transmitting station.

(3) It enables the operator to monitor the transmissions while a bearing is being taken.

The system comprises four antenna installations, each composed of five vertical antenna elements or monopoles. Each of the antenna installations is designed for a particular frequency band and feeds into a receiver and cathode-ray indicator. The

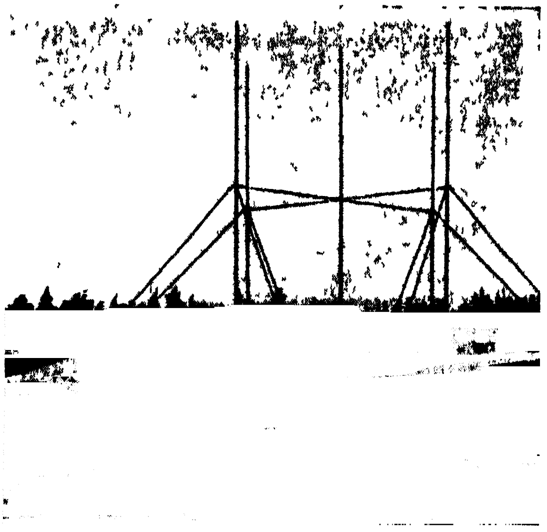


FIG. 15–42. The antenna arrangement employed in the Adcock direction finder. Four such antenna installations are employed to cover the frequency range from 1.5 to 30 mc.

monopoles are matched to the radio-frequency transmission lines, carried underground to the monitoring station, by means of coupling units which employ a cathode follower circuit in which the cathode and plate circuit resistors are so close in value that the output is matched to the balanced transmission line and equal voltages are applied to each half of the line in phase opposition. In other words, the coupling unit acts as a phase inverter from a single ended input (the monopole) to push-pull output (the r-f line) and its output impedance matches the impedance of the r-f line

In Figure 15–42, it will be observed that there is a vertical antenna installed at the intersection of the planes comprising the direction finding antennas so that the four d-f antennas form a square with the vertical antenna at the center. The energy from this center antenna is carried into the receivers through a coupling unit and r-f line much like the circuit associated with the d-f antennas. This central antenna permits determination of the direction of arrival of the radio signal and, provided propagation conditions are normal, the direction of the transmitting station.

The system is capable of taking bearings on transmitters operating between 1.5 and 30 mc provided the received signal is of sufficient intensity to produce a satisfactory pattern on the fluorescent screen of the cathode-ray bearing indicator.

When a bearing is obtained on a desired station, a pattern similar to that shown in Figure 15–43 can be read directly from the optical scale associated with the cathode-ray oscilloscope. Figure 15–44 shows the type of pattern produced when the sense antenna is cut into the receiving equipment. The equipment is installed and adjusted so that 0° or 360° point corresponds to a bearing of true north, hence the sense bearing shown in Figure 15–44 is 55° and not 235°, which is the reciprocal bearing.

The existing propagation conditions in general determine the type of pattern produced. The most preferable pattern is that comprised of double arrows, as shown in Figure 15–43, with the points resting on the scale and its central point in the exact center of the scale. If the pattern is good, sharp, and steady, the bearings will be accurate. If the pattern is moving, or shows the presence of interference or other irregularities, the bearing cannot be given the same accuracy classification. Under certain conditions of propagation and type of transmission, it will be observed that the bearing rotates through a 360° arc. Obviously, no bearing can be obtained under such conditions.

15–4k. Determination of Ship's Position by Radio Bearings—The most general use of the radio direction finder is to ascertain the true bearing, or line of direction of a radio beacon or radio station of known latitude and longitude. At the time the bearing is taken the ship will be somewhere on the line of direction, and if the position of the vessel as determined by dead reckoning or observations is correct, or nearly so, it should fall on, or close to the line.

The single bearing, or line of direction, can be utilized as a danger bearing, or more properly, a safety bearing; for example, if two ships are approaching each other during thick weather, or if one ship is overtaking another, a radio bearing can be taken and the angle from the ship's head noted. If other bearings are then taken at intervals of ten or fifteen minutes (depending on speed and estimated distance) the angle from the ship's head will

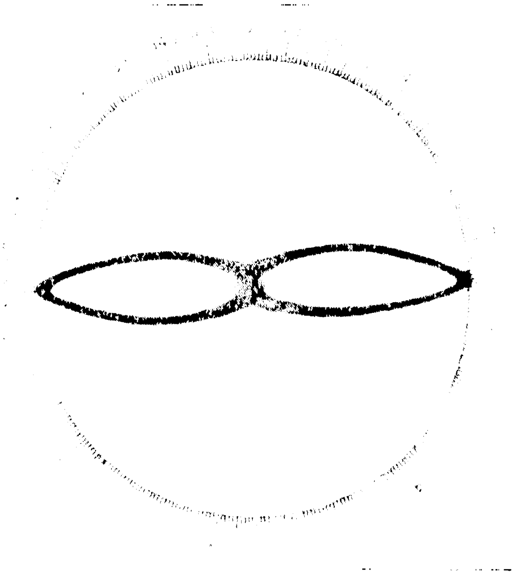


FIG. 15–43. Pattern of a bearing of good quality indicated on the screen of cathode-ray tube.

either be increasing or decreasing. If the angle is found to be decreasing it should be taken as a danger signal and the ship's course altered one or two degrees, or until the angle is found to be increasing, and the ships will pass with safety. The distance between the vessels can be roughly estimated with experience in noting how quickly the angle between the vessels changes. If the distance is, say, fifty miles or more, the angle will not show much change for some time, whereas if it changes quickly it can be assumed that the other vessel is quite close.

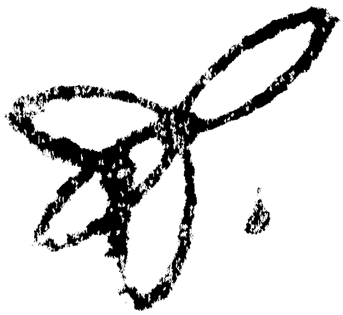


Fig. 15–44. The cathode-ray pattern by which the sense, or direction, of arrival of the radio wave is determined. The pattern in Figure 15–43 is in the form of a twin-leaf with both the true and reciprocal bearing. To distinguish the true bearing from the reciprocal, the fifth or center vertical antenna is connected through the goniometer. The appearance of the pattern is then changed as shown above. In this case the true bearing is 55 degrees.

The radio operator can be of considerable assistance in cases of this nature, as he can advise of any ships in the vicinity, and by listening on the head phones of the direction finder can identify the ships on which bearings are desired. He can also judge approximately by the strength of the signals whether or not the other ship is within a short distance.

The line of direction can be used to good advantage when running for a lightship equipped with a radio beacon, provided the precautions outlined previously are observed, namely the angle between the course and the radio beacon should increase for a vessel passing clear.

15–4l. Cross Bearings—If a single bearing taken to check the ship's position does not give satisfactory results, due to the angle of bearing, or possible error in noting reading of the direction finder, or figuring dead reckoning or observations, a reliable fix can be obtained by taking bearings on two or three radio beacons. If unable to pick up more than one radiobeacon, a radio telegraph station can be used, provided such station is on or close to the shore; it is not obstructed by intervening land; and its position accurately known. The ship's radio operator will again be of assistance in such instances to identify the station being used.

When the morning time sight is taken and a single line of position laid down, another line to cross it can be obtained by taking a radio bearing. The radio bearing should be taken simultaneously with the time sight. If there is any appreciable difference of time between them, due allowance should be made for the speed and course of the vessel, and the distance run. This will obviate the necessity of waiting until the sun changes its bearing sufficiently to obtain another position line which will cross the first at a good angle. This method can, of course, be used at any time of day or night when it is possible to obtain the altitude of a celestial body. Other similar uses of the radio direction finder can be devised, for instance, in approaching a harbor where it is possible to obtain a bearing of a distant mountain peak, or lighthouse, another bearing to cross the first can be obtained by radio.

15–4m. Precautions to be Observed—Whenever a radio bearing is about to be taken, the wheelsman should be told to stand-by and call out when the ship is on course, for if the ship has yawed off two or three degrees the bearing will be in error by a similar amount. On ships equipped with direction finders having a gyro repeater, the observer can himself determine when the ship is on the course.

If any doubt exists in the mind of the observer as to the accuracy of the observed bearing, or if the ship is yawing badly due to heavy weather, several readings should be taken and the mean reading used as the correct one.

15–4n. True and Relative Bearings—On vessels fitted with radio direction finders equipped with a movable dumb compass card, bearings can be taken either from the meridian or relative to the ship's head. On bearings taken to determine the ship's position, it is suggested that they be taken from the meridian, and if the dumb compass is adjusted to the true course (NOT magnetic) of the vessel, the observed radio bearing is the true bearing. On bearings taken on lightships or other vessels to determine their position relative to the ship's head, the direction finder dumb compass should have its 0–360 mark set on the lubber line. Bearings taken in this manner will give the bearing or angle in degrees from the ship's head. If the angle from the ship's head on the port side of the vessel is desired, the observed reading is subtracted from 360 to give the desired result.

It is again suggested that occasional check bearings be taken when passing radio beacons under conditions of good visibility. Radio bearings should check with pelorus or azimuth compass bearings. Distance from the beacon should be at least two miles. Visual bearings in doubt due to rolling of vessel should be rejected. Such check bearings will serve to assure the master of the accuracy of the instrument. Whenever any large metal objects are added to or removed from the ship's deck structure the direction finder calibration should be checked, particularly through the arc in which the object is located, and if any unreasonable errors are detected steps can be taken to have these corrected.

15–5. Mackay Radio Direction Finders Types 106B and 106BD—Radio direction finders types 106B and 106BD are suitable for marine or land station use and are designed for accuracy, sensitivity, selectivity, together with simplicity of operation, installation and servicing. They are constructed in a rugged, substantial manner with the use of non-magnetic materials wherever possible. The frequency range of the direction finder is 255 to 550 kc.

The direction finder proper is a compact single unit designed for suspension from the ceiling or pilot house roof. There is a separately mounted battery box housing a storage battery for "A" supply and either "B" batteries or a dynamotor for plate supply. The two direction finders are identical, except that the type 106B utilizes "B" batteries while the type 106BD utilizes a dynamotor.

A shielded loop 27 inches outside diameter is mounted on a large pedestal, the lower end of which passes through the deck to support the indicator and receiver cabinet assembly. The height of the pedestal is such that the lowest part of the loop winding is 6 inches above the hand rails to be found on most vessels. The loop winding is completely enclosed in a water-tight housing made up of 3 inch outside diameter copper tubing bent to form a circle of 27 inches outside diameter. A bakelite insulated joint is used at the top and a bronze casting with ball and sleeve bearings at the bottom. All fittings are securely brazed to the tubing to provide strength and rigidity. The complete assembly is designed to withstand without damage the strongest gales encountered on shipboard.

The loop winding consists of 18 turns of No. 14 stranded, rubber covered wire supported on a system of bakelite spreaders to obtain minimum distributed capacity and a symmetrical winding. The lead wires are brought down the drive shaft on circular insulators and are amply spaced for low capacitance. The center tap is also brought down to the receiver so that it may be disconnected from ground for a leakage check. The complete shielding of the winding and leads eliminates any antenna effect of the loop and greatly reduces induction noises from electrical machinery in the vicinity of the installation.

The loop is rotated by means of the direct drive handwheel mounted below the receiver cabinet, the loop drive shaft passing through the receiver cabinet and indicator housing to connect with the loop above. A friction brake is provided on the indicator for locking the loop in place when desired.

The indicator is of the mechanically compensated fully automatic type in which the pointer, showing the loop bearing, leads or lags behind the actual loop position to compensate for radio errors determined during calibration at the time of installation. It makes use of a stationary cam and a movable roller with associated linkage to actuate the pointer. A maximum correction of plus and minus 22° can be obtained on the cam. The indicator face carries a large full vision dial showing the figure of a ship at its center, to aid the navigator in visualizing the bearings obtained with the equipment. A movable outer scale divided into 360° is provided for obtaining true bearings. The indicator is designed so a Sperry repeater motor may be installed to operate the movable outer scale, and thus maintain the true course reading on that scale at all times. "Off bow" bearings may be taken from the inner stationary scale. The long end of the pointer indicates the bearings on the outer scale while the short end of the pointer is used in conjunction with the sense button on the receiver to remove the 180° ambiguity

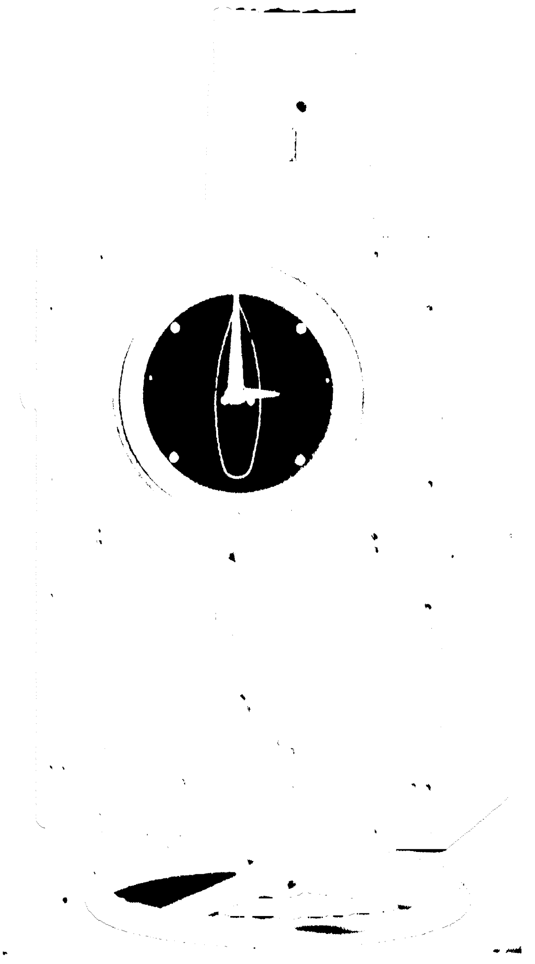


FIG. 15–45. Mackay radio direction finder type 106-B.

from the direction pointer readings. A glass cover protects the dial and pointer from damage.

The rear of the indicator housing encloses the loop collector ring and brush assembly and the spring meshed bevel gears for driving the compensator assembly. The collector rings and brushes are of monel metal to prevent corrosion or noisy operation. A bakelite terminal board is provided for securing the antenna and loop leads which connect to the receiver below. Oil and grease cups have been provided on the loop and indicator bearings, the design being arranged to confine the lubricant to the desired surfaces.

Two small holes on the sides of the indicator serve to drain off any moisture condensate from within the loop pedestal and condensation within the loop will run down inside of the loop shaft and drain off below the loop handwheel.

The receiver type 2B is a single control tuned radio frequency type employing eight 6.3-volt heater type tubes. The tuning range is from 255 kc to 550 kc. The dial numbers increase with frequency and the points 290 kc, 300 kc, 310 kc, 375 kc, and 500 kc are calibrated and engraved on the scale.

The other controls on the panel are the intensity control, antenna balance control, sense button, ICW–CW switch, Off-On switch and phone jack. The loop capacitance and adjusting condenser is located under the receiver chassis as it is set only at installation and then locked in place. The sense effect rheostat is likewise located on the under side of the chassis.

The schematic diagram of the direction finder is shown in Figure 15–46. The first r-f stage of the receiver consists of two 6SK7 pentode tubes connected in push-pull and fed directly from the tuned balanced loop. The succeeding two stages are tuned with twice the inductance and half the capacitance of the loop circuit and each employs a 6SK7 tube. The 6J5 triode detector is fed from an untuned transformer peaked at 255 kc, thereby compensating for the falling gain characteristic of the tuned stages.

The audio amplifier consists of one resistance coupled and one transformer coupled stage employing type 6J5 tubes, with an output transformer to match a pair of 20,000 ohm phones.

The beat frequency oscillator is a 6J5 triode tube feeding the detector circuit only through stray coupling. The tuning condenser of the oscillator is one gang of a three gang condenser, the other two gangs comprising the r-f amplifier tuning condensers. All three gangs carry trimmers for adjusting the minimum circuit capacitance. The beat note frequency is not affected by signal strength.

The loop tuning condenser is connected to the above condenser by means of an insulated flexible coupling.

Careful shielding of individual units in the receiver, in addition to the complete shielding of the receiver cabinet, makes the installation free from stray signal pickup and removes any couplings which may affect the accuracy of the bearings. The vacuum tube circuits are properly by-passed to prevent interaction between the amplifier stages, and the battery leads are by-passed at the receiver cabinet terminal board to prevent any pickup by the battery cable.

The intensity control potentiometer controls the cathode voltage of the r-f amplifier tubes, making it possible to take bearings on very strong signals without overloading the receiver. The operation of this control has no effect on the receiver selectivity, frequency of the beat note, or the adjustment of the balanced condenser. The width of the minimum may be set by this control to give a sharp null point, free from residual signal. The null point is not shifted by changes in the tuning control or balance condenser.

Provision is made for an interlocking control circuit and signal system between the direction finder and the ship's radio room. A red signal light in the radio room lights up when the direction finder is turned on, and remains lit all the time that the direction finder is in use. Furthermore, the main antenna switch in the radio room is connected in series with the main transmitting antenna, and contains auxiliary contacts which close only when the switch is thrown to open the antenna. If the direction finder is turned on and the auxiliary contacts on the main antenna switch are closed, a relay in the direction finder receiver operates, removing a ground from the sense antenna and connecting the heater circuit of the receiver to the A battery. A green signal light on the receiver panel lights up, showing that the direction finder may be used to take bearings. At the same time that the relay in the receiver operates, a second relay in the battery box closes and turns on the B batteries or the plate supply dynamotor.

The B battery current drain of the receiver is 4 to 18 ma at 90 volts, the higher value being for the maximum setting of the volume control. The A battery current drain of the complete installation is 3.8 amp at 6.3 volts for type 106B, and approximately 6.2 amp for type 106BD.

The batteries for operation of the type 106B radio direction finder are contained in battery box type 4B, supplied with the equipment, and consist of a 6-volt 50 ampere-hour storage A battery and two 45-volt B batteries. Type 106BD utilizes a dynamotor for B supply instead of B batteries and the A battery is 6 volts 80 ampere-hour capacity. The dynamotor plate supply assembly, including ripple filters and a relay is mounted in battery box type 5A together with the storage A battery. The battery box terminal board is connected to the receiver, radio room and ground. A fuse lamp or 1⁄16-amp

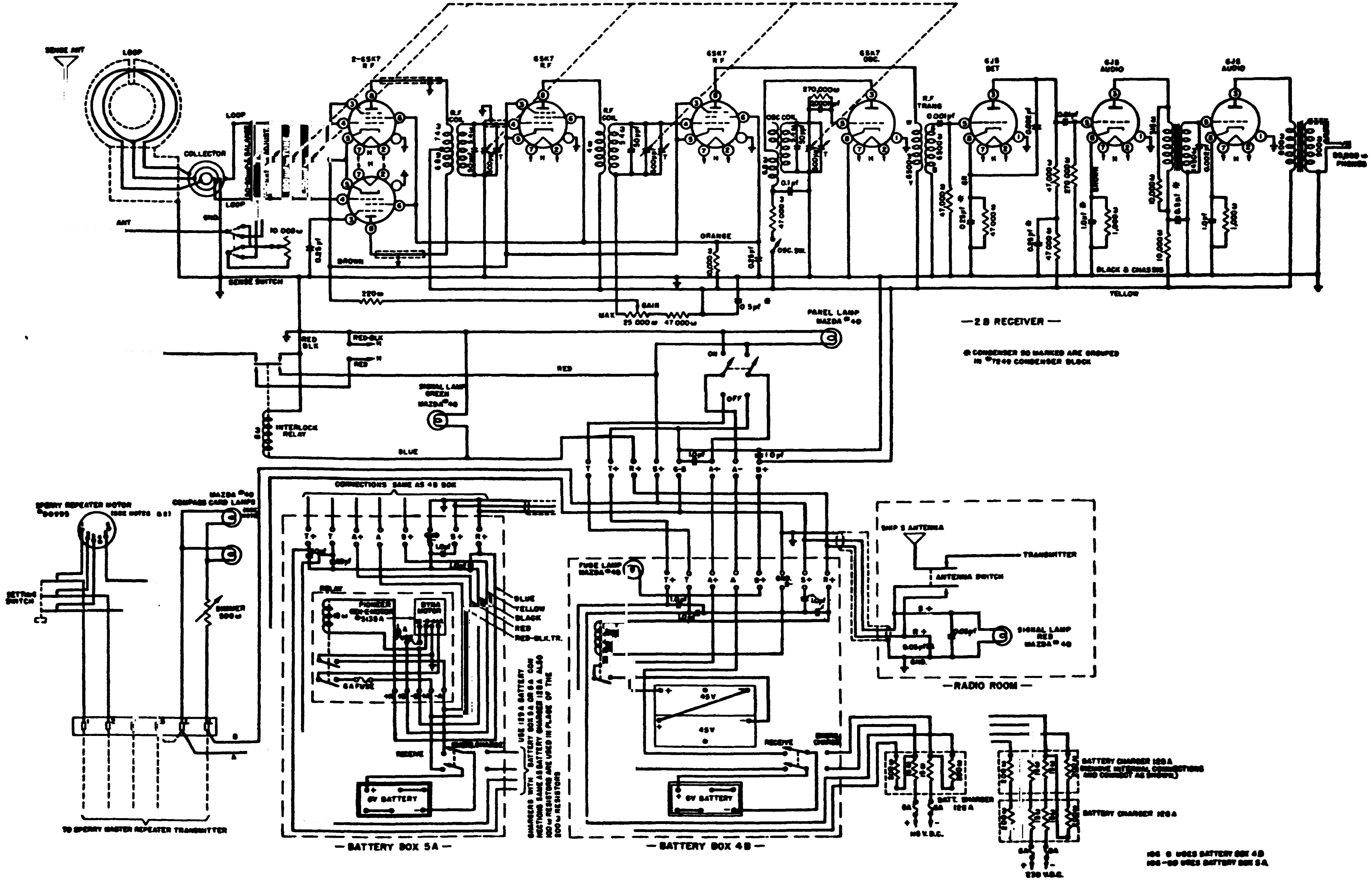


Fig 15–46 Circuit diagram Mackay radio direction finder 106B and 106BD

fuse is connected in series with the plate supply to prevent damage to the receiver, batteries or dynamotor in case of a short circuit. By-pass condensers are connected across the signal light line and the trickle charge line to prevent any interference getting into the receiver from these sources.

Battery charger 128A is used with type 106B, and battery charger 129A with type 106BD radio direction finder. These units house the resistors for trickle charge and emergency full charge, the charging current being derived from the 115-volt d-c line.

The OFF-ON switch on the receiver panel, when in the OFF position, places the storage battery on trickle charge (0.25 amp for type 106B, and 0.5 amp for type 106BD). A switch is provided on the battery box, which is normally set on the RECEIVE position. However, if the charge in the storage battery becomes low, this switch is to be thrown to the EMERG. CHARGE position, which places the battery on a 3.5-amp charge.

The 6A indicator used in these direction finders has been designed to make use of a Sperry no. 80995 repeater motor to drive the bearing scale. Two Sperry No. 96666, 70-volt 8-watt lamps are used for illumination of the indicator. A Sperry No. 65914 gyro compass filter should be installed in the master repeater transmitter to eliminate induction noise from the transmitter contacts.

If the direction finder is installed without the Sperry equipment the 6.3-volt lamps originally supplied are used for illumination and the bearing scale is set by hand to the desired reading by means of its setting knob.

15–5a. Features

1. *Loop:* 24-inch mean diameter, shielded and balanced. Winding of 18 turns. Inductance 323 microhenries at 1000 cycles; 313 microhenries at radio frequencies. Distributed capacity $= 100\ \mu\mu f$ at radio frequencies. $Q = 160$ at 500 kc. $Q = 200$ at 255 kc all for complete loop measured at receiver terminal board.

2. *Indicator:* Automatic type with vertical full vision dial. Maximum correction plus and minus 22° by means of cam cut at installation. Low-loss collector ring and brush assembly designed for freedom from noise and corrosion are located in indicator housing where they are protected from moisture, condensation, and dirt. A Sperry repeater motor may be installed.

3. *Condensation:* Provision made to prevent accumulation of moisture due to condensation or leakage by adequate system of drainage. Loop housing and bearings carefully weather-proofed to prevent entrance of moisture into direction finder structure.

4. *Circuit:* 8 tube TRF with push-pull input and 6.3-volt heater type tubes. Completely shielded.

5. *Frequency range:* 255 to 550 kc.

6. *Sensitivity:* Average better than 0.25 microvolts for 6 milliwatt output measured through loop at above frequencies. An output of 6 milliwatts is obtainable when the loop is rotated to maximum signal in a field of less than 10 microvolts per meter at all frequencies in the range.

7. *Selectivity:* Bandwidth measured at ratios of input voltage off resonance to input voltage at resonance.

Ratio	*Bandwidth in % Resonant Frequency*
10	Less than 2.5%
100	Less than 6%
1000	Less than 12%

8. *Fidelity:* Flat within 5 db from 250 to 2000 cycles; down at least 15 db at 100 cycles and at 5000 cycles.

9. *Output impedance:* 20,000 ohms at 1000 cycles.

10. *Signaling System:* Connections may be installed so that turning on receiver lights a signal lamp in the radio room. Relay in receiver is operated by antenna switch in radio room, making use of receiver impossible unless transmitting antenna is opened.

15–5b. Maintenance—Routine inspection of the apparatus should be made about once a week. All battery voltages should be checked with the receiver in operaiton, and if necessary the storage battery placed on EMERG. CHARGE. Add water as required. The B batteries should be replaced if either one measures less than 38 volts under load.

The lubrication of the equipment should be inspected every six months and replenished if necessary. The oil cup on the upper loop bearing should be filled with medium machine oil. The wick oiler on the pointer shaft inside the indicator housing should be filled with medium machine oil and the two grease cups on the indicator sleeve should be screwed in one half turn. When the grease cups are empty, the caps should be removed and filled with medium cup grease. Care should be taken to prevent an excess of lubricant from running out of the bearings.

If the loop collector rings become dirty, they may be polished with very fine sandpaper or crocus cloth, after wiping clean with alcohol. Do not use emery paper.

The equipment should also be inspected mechanically to make certain that no screws or other fastenings have been loosened by vibration or damage.

In case it is suspected that the receiver tuned circuits are out of alignment, the following procedure should be followed. The two condenser gangs should be lined up so that the rotor plates of each are *exactly* flush with the stator plates at the position of maximum capacitance. This adjustment is made fixed by the set screws in the insulated coupling between the two gangs. The drum dial should then be set so that the scale reads "0" with the condenser gangs at the maximum position. This adjustment is made fixed by the square head set screws in the hub of the drum dial. Adjust the trimmers on top of the gang for maximum output on a 500-kc signal with the dial set at 72.5. The loop adjusting condenser located underneath the chassis should also be adjusted at this frequency and then checked at 300 kc. If the position of this unit varies it should be set closer to the 500-kc than the 300-kc point. The beat oscillator trimmer (farthest from the drum dial) should be set to give a beat note on all tuning frequencies throughout the scale.

The mechanical calibration of the direction finder may be checked by comparing the readings of the direction pointer and the checking scale on the handwheel to see if the difference agrees with the original calibration data. If any change has been made in the rigging or structure of the vessel it may be necessary to recalibrate the direction finder, or at least check the radio calibration by simultaneous radio and sight bearings taken on a radio beacon or ship station at several points around the indicator dial.

In cases of erratic bearings look for intermittent grounds or open circuits in the rigging or antennas on the vessel.

Broad bearings may be observed if the main transmitting antenna is grounded.

If the construction of the vessel is such that a vertical antenna can be erected, a length of 16 to 30 feet will be required. Where the antenna must be inclined forward or aft and at a slope not much above the horizontal, the length will have to be greater, such as 25 to 60 feet. Another useful configuration is to run the antenna vertical about 10 to 15 feet and the horizontal or sloping part about the same distance.

It is well, where possible, to avoid running the sense antenna too close to the loop. A horizontal run, on insulators, about 8 or 10 feet before starting the vertical portion will accomplish this.

Avoid shielding the sense antenna lead-in any more than necessary, as this reduces its effectiveness. Run the unshielded wire on small insulators, keeping it away from power wires or other sources of induction noise. If the lead-in is run down inside the pedestal tubing, that portion must be shielded. However, it is frequently preferable to run the unshielded lead-in down the outside of the pedestal tubing and to enter the cabinet near the terminal provided for the lead-in. This entrance should be made water-tight, especially if it is on the top of the cabinet.

After completing the installation, a test of the direction finder will demonstrate whether it is desirable to lengthen or shorten the sense antenna. If it is too short, there will not be sufficient range on the BALANCE control to obtain a good quiet null, and the sense effect will be inconclusive. If the sense antenna is too long, the BALANCE control will be very sharp and critical to adjust. It has been the experience of those who have made many direction finder installations that each vessel is different and that a sense antenna which is very good on one vessel will be found to be too long or too short for another.

Noises in the receiver itself may be caused by loose battery connections, broken wires or poor contact of a tube in its socket. Open filter condensers in the dynamotor supply will result in receiver noise.

Noise observed when the loop is rotated rapidly may be caused by dirty collector rings and should be corrected by cleaning the rings as directed above.

Induction noises from electrical machinery on the vessel should be traced to the machine causing the trouble and filter condensers connected across motor commutators or other spark producing elements.

15-5c. Calibration—While proceeding directly toward the radio beacon with the loop adjusted for minimum signal and the direction pointer at zero, correctness of the sense indication may be checked by pushing the sense button and noting that the maximum signal occurs with the sense pointer at or near zero. If the sense pointer is toward 180° for maximum signal the loop leads will have to be reversed. Adjust the sense potentiometer for maximum sense effect. One loop lead is painted yellow at its end (or carries a cable marker in order to identify it in case it is necessary at any time to remove the leads. A pencil mark should be placed on the shield adjacent to the terminal to which the marked lead is attached.

The direction pointer may be adjusted for radio zero by means of the two set screws in the vertical bevel gear inside the compensator. After tightening these screws the apparatus is ready for calibration which is done in the usual manner by making a circle in front of the beacon while observing the radio minima and the pelorus readings simultaneously. The points so obtained are plotted on the standard curve sheet and then transferred to the etched cam furnished for this purpose. The cam is then cut out carefully and filed smooth after which it replaces the zero cam in the front of the compensator.

After cutting and replacing the cam, check the readings of the checking scale against the corrected radio bearings on the indicator scale. Tabulate the two sets of readings and compute the error of each reading. Remove the cam and file it out where necessary to compensate for these errors. This is particularly important where the cam has steep sides resulting from the compensation of large radio bearing errors.

15-5d. Sense Antenna—No fixed rule can be formulated for the erection of a successful sense antenna. However, several suggestions can be given as a guide in installing the antenna.

15–5e. Operation Instructions. (Refer to Figure 15–47.)

(*a*) *Ship's antenna.* The ship's radio antenna must be OPEN while the radio direction finder is in use, that is, entirely disconnected from transmitter, receiver, and ground. A positive check on this condition is provided by means of a special antenna switch and signal lights. The green light (U) on the radio direction finder receiver indicates that the ship's antenna is open, the red signal light unit (CC) indicates that the radio direction finder is in use.

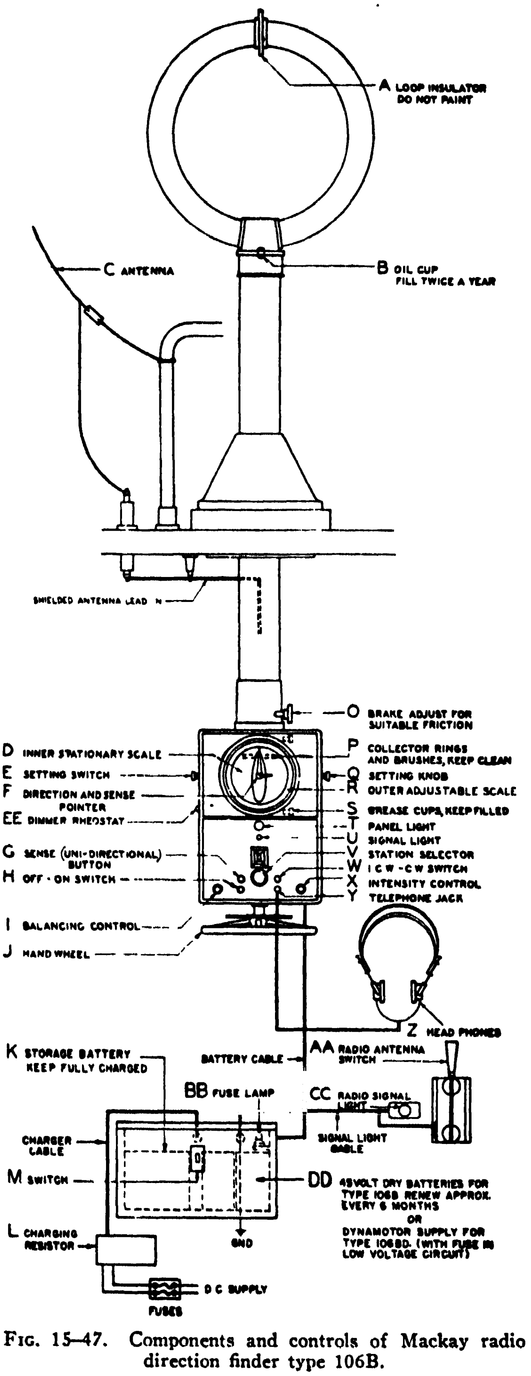


FIG. 15–47. Components and controls of Mackay radio direction finder type 106B.

(*b*) *Receiver.* The receiver is housed in a cabinet and should be kept closed at all times. Four type 6SK7 or 6SK7–GT and four type 6J5 or 6J5–GT tubes are used. One or more spare tubes of each type should be carried. The headphones are provided with a plug which is inserted in jack (Y) on the receiver front panel.

(*c*) *Batteries.* The 6-volt storage battery (K) must be kept fully charged and filled to the proper level with distilled water. When the OFF-ON switch (H) on the panel of the receiver is turned to the OFF position the battery is automatically placed on trickle charge. Under normal use such charge will be sufficient. However, if at any time the charge in the battery is found to be low, the switch (M) on the battery box should be turned to the EMERG. CHARGE position. When the battery is fully charged, turn switch (M) to RECEIVE, in which position it should always be left, except as directed above.

Radio direction finder type 106B utilizes two 45-volt B batteries (DD) which should be renewed approximately every 6 months, or sooner if the voltage of either battery drops below 38 volts with the receiver in operation.

Radio direction finder type 106BD utilizes a dynamotor for B supply, which should require infrequent attention.

(*d*) *Indicator.* The indicator is automatically compensated to give true radio bearings. It is provided with a brake (0) so that the loop may be locked in position when desired.

Two scales and a pointer are provided in the indicator. The pointer (F) is permanently fixed to the handwheel and indicates the bearing of the signaling station from the ship's bow, or zero on the inner scale (D).

The outer scale (R) may be set at any position desired with respect to the inner scale by means of the setting knob (Q), after operating setting switch (E).

The bearing of the signaling station from true north may be read directly from the outer scale if the ship's true course is set on the outer scale with respect to zero on the inner scale.

(*c*) *Checking calibration and adjustment.* The accuracy and calibration of the radio direction finder may be checked from time to time in clear weather by means of simultaneous sight and radio bearings on shore stations or other vessels.

1. *To Take Bearings When the General Direction Is Known:*

(a) Open ship's antenna and do not attempt to take bearings until the illumination of the receiver signal light (U) shows that the antenna *is open.*

(b) Ascertain that the switch (M) on the battery box is turned to the RECEIVE position.

(c) Plug headphones into telephone jack (Y) and adjust to ears.

(d) Turn switch (H) to ON position.

(e) Turn switch (W) to ICW if a spark or interrupted CW beacon or station is to be received, or to CW for continuous wave beacons or stations.

(f) Adjust the station selector control (V) back and forth to a position where the desired signal is hear with maximum intensity. The signal strength is then controlled by adjusting the intensity control (X).

(g) Now rotate the handwheel so that the long end of the direction pointer (F) points in the general direction of the signalling station and move the handwheel back and forth to a position of MINIMUM intensity, at the same time adjusting the balancing control (I) to a position of MINIMUM signal intensity and read the bearing.

(h) In cases of long distance bearings if the sector of minimum signal is broad, the bearing can be determined quite accurately by splitting the silent sector.

2. *To Take Unidirectional Bearings When the General Location Is Not Known:*

(a) Before taking a unidirectional bearing, it is necessary to obtain a minimum signal as noted under paragraph (g) above. At this time no attention need be paid to the pointer.

(b) Then depress and hold down sense button (G) and rotate the handwheel through 360°. Maximum signal strength will be obtained only when the SHORT END of the direction pointer (F) points in the general direction of the signaling station.

(c) After determining the general direction of the signaling station, the bearings can then be established by following the instructions of paragraph (f) to (h) above.

15–6. RMCA Model AR–8703–BX Radio Direction Finder—The RMCA model AR–8703–BX radio direction finder employs a highly developed eight-tube superheterodyne receiver, the circuit schematic of which is shown in Figure 15–49.

The main receiver tuning control, which is connected to the four-ganged condenser, is calibrated in kilocycles. The specified tuning range is 270 to 520 kc, with a small overlap at each end. Attention is directed to the red sector on the tuning dial for 285 to 315 kc beacon band. Note that the tuning dial provides markings every 2 kc from 270 to 320 kc and every 10 kc from 320 to 520 kc.

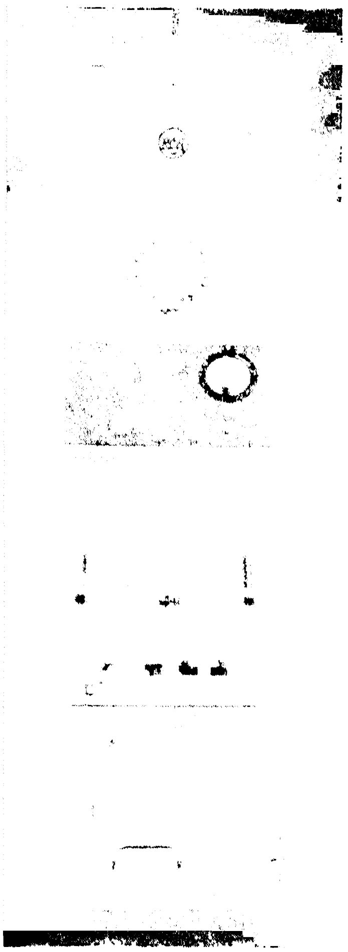


FIG. 15–48. RMCA model AR-8703-BX radio direction finder.

The balance is the standard Radiomarine magnetic balance with sense position, and is controlled from the receiver panel.

The master switch, controlled from the receiver panel, is a six-pole double-throw unit. Two poles are not used. In the OFF position, the switch short-circuits the loop, grounds the sense antenna, disconnects plus 90 volts and de-energizes the relay which stops the dynamotor and places the A battery on charge through the charging lamps. When the master switch is placed in the ON position, it removes the short from the loop and the ground from the sense antenna, closes the 90-volt plus B circuit and energizes the radio room red light. When the radio operator closes his interlock switch, this energizes the binnacle relay, applying six volts to the receiver and the panel lights and starts the dynamotor.

The CW switch on the receiver panel controls the plate circuit of the 6SJ7 oscillator tube, so that incoming signals may be heterodyned. The output of

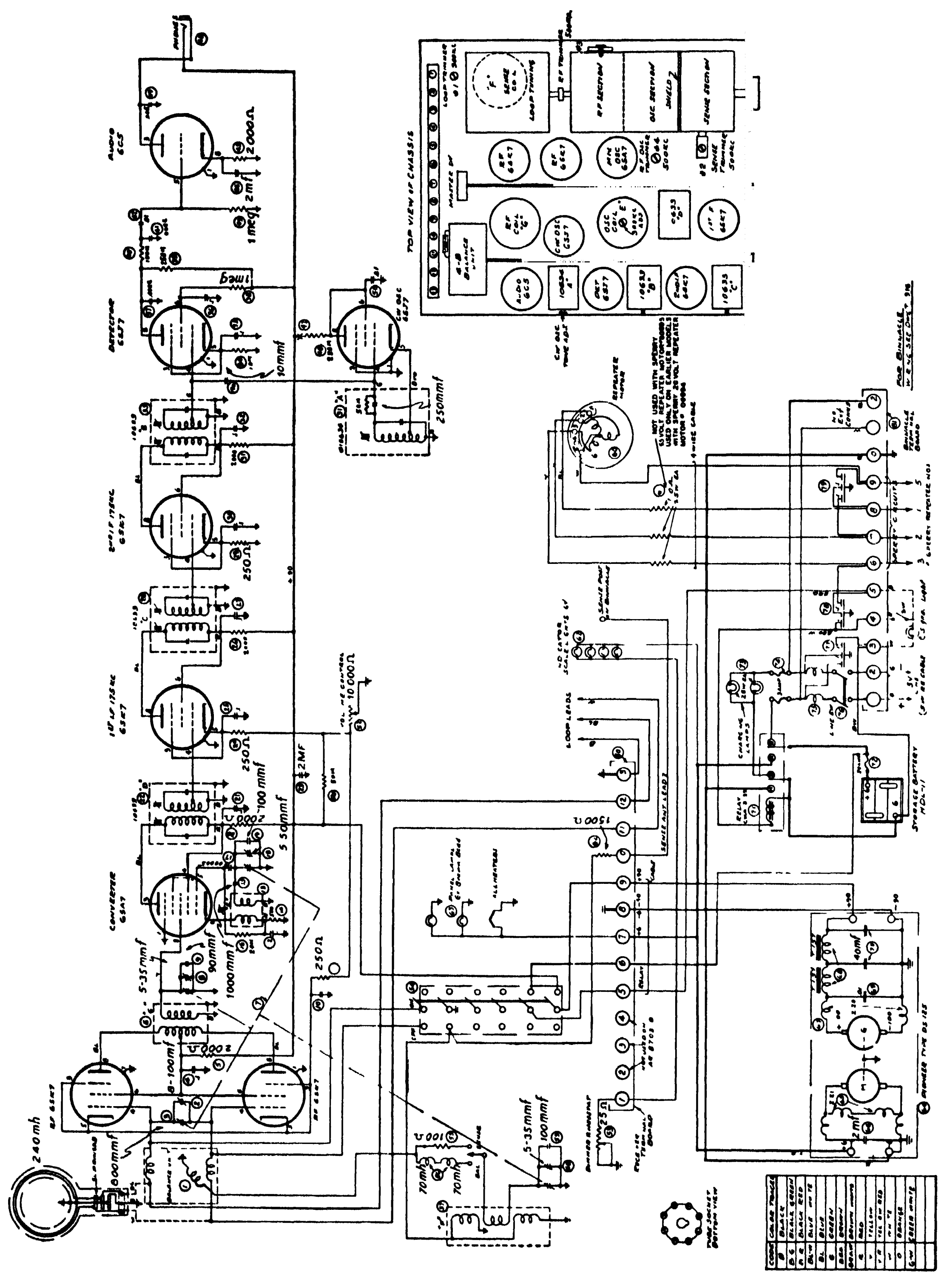


FIG 15–19. Schematic diagram of model AR-8703-BX radio direction finder.

the oscillator tube is loosely coupled to the grid of the second detector tube. The CW oscillator is adjusted to operate at 174 kc so as to provide a 1000-cycle beat note with the 175-kc intermediate frequency. The adjustment for the CW oscillator is a small knurled nut on the transformer can marked "A." If it is found necessary to adjust this unit, a modulated signal should first be accurately tuned in with the CW switch in the OFF position, and then leaving the main tuning dial unchanged, adjust the oscillator can "A" for a suitable beat note. Due to the high selectivity of the receiver, this adjustment must be made with care, and it is important to insure that the incoming signal is accurately tuned.

Each receiver is carefully aligned and adjusted in the laboratory with precision instruments and field personnel are cautioned not to disturb any adjustments unless a definite procedure is followed, together with a full understanding of the circuits involved. Under normal circumstances, the only receiver adjustments which should be made by field personnel are lineup of the loop circuit by means of the loop trimmer capacitor (No. 1) and adjustment of the sense trimmer circuit (No. 2). The main loop tuning condenser, which is ganged with the other three-section condenser, should not be disturbed as all four variable condensers should be fully meshed when the main tuning scale is set at its last major division (260 kc).

15–6a. Grounding—A ground stud at the rear of the binnacle near the stuffing glands is provided, and it is very important to run a good low-resistance ground connection between this stud and the ship ground. Do not depend on the binnacle ground obtained through the binnacle base mounting studs. Failure to observe this precaution may result in noise in the receiver from the incoming power circuits. Attention is directed to the filter system built into the binnacle. The 110-volt charging circuit passes through a pair of radio frequency chokes, and on the "load" side of these chokes 0.1-μf filter condensers are connected to suppress induction. Additional 0.1-μf filter condensers are mounted in the binnacle to provide radio-frequency by-passing for the 7 additional incoming leads. These additional condensers may either be connected or disconnected as determined by trial if induction is present.

15–6b. Sense Circuit Adjustment—The sense circuit should be adjusted in the following manner. Take a bearing on a signal of known frequency on 500 kc, or as near to this frequency as possible. Place a temporary short circuit around the 100-ohm resistor on the balancer unit. Hold balancer in "sense" position, and adjust the sense trimmer marked No. 2 on the chassis for maximum signal. Adjust the volume control at the same time so that resonance, as indicated by adjusting the trimmer condenser, is clearly defined. Then lock this condenser and remove the short from the 100-ohm resistor. Next, rotate the loop toward lower readings from the bearing point and check that the signal increases more than it does when the loop is rotated the same number of degrees toward higher readings on the scale. If this effect is not obtained, reverse the loop leads to terminals 11 and 12 on the receiver chassis and check again for correct sense indication. Sense action should then be checked on a signal around 300 kc to insure that a proper indication of sense is obtained. Do not adjust sense trimmer condenser on signals in the beacon band, as resonance will not be obtained.

15–6c. Alignment—The loop trimmer condenser marked No. 1 on the chassis should always be adjusted for maximum signal when the receiver is accurately tuned to a beacon frequency. First, tune the signal with the main tuning control for maximum output. Then regulate the volume control so that the signal is fairly weak and adjust No. 1 loop trimmer condenser for maximum response.

The following adjustments should not be attempted unless it is definitely known that the entire chassis requires realignment. Tune in a signal of *known frequency* in the beacon band. Observe if the main tuning dial calibration is accurate. If, for example, the known signal is 314 kc, set the main tuning dial at 314 kc and leave it there whether or not the signal is heard. Then adjust the 300-kc oscillator adjustment on can marked "E" until the signal is heard and until it is a maximum. Loop trimmer condenser No. 1 should always be adjusted for maximum without disturbing the main tuning dial and using a low enough setting on the volume control so that resonance is clearly observed. Next, tune the receiver to a known 500-kc signal; *leave the main tuning dial at 500 kc*, and adjust the 500-kc oscillator trimmer No. 4 and 500-kc r-f trimmer No. 3 until the signal is heard at a maximum. It is emphasized that all such adjustments should be made by setting the main tuning dial exactly at the calibrated point for the known frequency, as otherwise the calibration on the tuning dial may not hold throughout the range.

The intermediate frequency of the receiver is 175 kc. No attempt should be made to align all the i-f transformers (transformers "B," "C" and "D") on incoming signals. I-f transformers are of special design, and will not drift out of adjustment in service. If, however, any *one* of these transformers requires replacement in the field, it may be aligned by tuning in a signal and then adjusting the two iron cores with the adjusting screws on the can, using a low volume control setting during this work. Since the i-f transformer adjustments are only accessible readily from the sides of the can, it will be apparent that such adjustments should properly be made with the receiver out of the chassis and with an accurate 175-kc modulated oscillator.

15–6d. Storage Battery Circuits—The storage battery to be used with the AR-8703-BX should be an HDL-11 or equivalent. This battery has sufficient capacity to operate the direction finder for a continuous period of approximately 16 hours. The total drain from the battery is 5.6 amp. The dynamotor requires about 2 amp, receiver tubes 2.2 amp, and the radio room red light,' indicator and panel lights and relay coil about 1.4 amp. Mazda No. 40 brown bead compass and panel lights should be used to insure minimum current drain.

A 25-ohm rheostat, connected in series with the compass indicator light, is mounted on the receiver panel. The purpose of this rheostat is to enable the navigator to adjust the brilliance of the main compass scale to the desired degree. Attention of the ship's personnel should be called to this feature.

The 110-volt battery charging circuit is disconnected when the small toggle switch at the rear of the binnacle is thrown to the OFF position. The 110-volt charging circuit is fused by 3-amp fuses while the positive side of the storage battery circuit is fused by means of a 20-amp fuse.

15–6e. Calibration—Calibration of the model AR-8703-BX radio direction finder should be carried out using standard Radiomarine procedure. A true "dead ahead" radio bearing should be taken and the loop firmly locked in position. Access to the calibrating scale, beneath the handwheel, should be obtained by removing the front half of the cover over this scale. The drum on which the scale is mounted may then be loosened from the drive shaft and reset so that the pointer reads zero. Then tighten up set screws and replace cover. The ship should then be swung in the usual manner and simultaneous radio and pelorus bearings taken at least at every stud point throughout the the azimuth so that an accurate calibration curve may be drawn. The loop pointer over the main compass scale should then be adjusted to zero and compensator adjusted to correct for the observed errors. Care should be taken not to strain the band when adjusting the band on the compensator. If a correction in excess of 25° is required, which results in extending the band toward its limits, it is recommended that a special long band be installed. After the compensator has been adjusted, the accuracy of the compensator setting may be readily checked by comparing readings of the pointer over the fixed outer scale against the readings on the calibrating scale.

15–6f. Maintenance—For ordinary use of the direction finder for approximately one hour per day, with 110-volt d-c supply, the charging lamps should consist of two 25-watt 120-volt lamps. These are connected in parallel in the binnacle. If the direction finder is used for longer daily periods, a pair of 40-watt or 50-watt lamps may be used. In the case of 240-volt ship supply, for one hour daily service, two 50-watt lamps are recommended.

Collector rings and brushes are made of solid silver, and must not be cleaned with abrasives. Use carbon tetrachloride on a clean cloth.

Light grease should be used on compensator gears and light oil on shaft bearings, taking care not to use excessive amounts.

The main line toggle switch behind binnacle must be turned OFF, or the 110-volt circuit disconnected in radio room, when ship lays up or is in drydock. Otherwise, the A battery will discharge back through power line.

CHAPTER 16

RADIO WAVE PROPAGATION

The history of radio wave propagation is a fascinating one; it begins with the famous equations derived by a British mathematical physicist, James Clerk Maxwell, in 1865 and 1873. Today as engineers and physicists explore the behavior of radio waves in the ultra-high and microwave spectrum, they must make use of Maxwell's equations derived 80 years ago.

In these equations, Maxwell worked out the fundamental laws governing the propagation of electromagnetic waves through space or through any medium. By separating the variables in the formula, he discovered that both the electric and magnetic fields were subject to the partial differential equation known as the "wave" equation. He determined that electromagnetic phenomena were essentially wave phenomena and, incidentally, showed that light itself was an electromagnetic wave. Ironically, Maxwell did not know of any waves produced by electrical means, since it was not until after his death that Heinrich Hertz, in 1888, demonstrated the existence of waves which were undeniably electromagnetic.

Hertz conducted his experiments first with wired circuits and then advanced to space transmission. In two experiments, Hertz employed the oscillatory discharge of a spark discharge to excite his loop antenna, the dimensions of which produced waves having lengths of 0.66 and 9.8 meters, respectively. Employing a loop of the same dimensions of the oscillator for a resonator or receiver, he discovered that at certain distances from the oscillator a spark would jump across a small gap at the ends of the receiving loop antenna. Since the wave lengths were short, he required only short transmission line lengths and reflection spacing distances to demonstrate the wave properties of this phenomena. In this way, Hertz verified the theories of Maxwell in every particular and established the close relation between the wave he generated and light waves. He proved the laws of wave propagation, showing that when propagated in straight lines they could be reflected by polished metal mirrors and could be focused or beamed by using lens-shaped cylinders of pitch.

As a result of these experiments, Hertz arrived at the conclusion that there must be a special medium other than air in which these waves traveled and that this medium transmitted waves of light. Thus originated the theory of the existence of an all-permeating medium which scientists called the *ether* and which eventually led to the identification of radio waves as ether waves. The fact that other types of wave motion capable of transmitting energy, such as sound and water waves, are dependent on a material medium, led scientists to the posulation of a nonmaterial medium called the ether, which must be assumed to permeate all space. As this theory developed, the reference to ether waves gradually changed to electromagnetic waves, since scientists have questioned the existence of ether as an all-permeating medium.

Other scientists carried on experimental work, and in 1895 Guglielmo Marconi produced apparatus that was capable of communication over a distance by means of radio waves. It was in this same year that Marconi decided on using a transmitter, one terminal of which was connected to the antenna and the other to earth. This was in contrast to the Hertz ungrounded dipoles, and resulted in increasing the range of communication. Today frequent reference is found to the Marconi antenna, which requires the transmitter to be operated against ground.

Oliver Lodge, in England, contributed the tuning principle and Braun, in Germany, made many fundamental studies, and on December 12, 1901, Marconi intercepted the first radio signals transmitted across the Atlantic between Poldhu on the Coast of Cornwall in England and St. John's, Newfoundland, using a wave length of about 1100 meters.

It is interesting to note that prior to transmitting radio signals across the Atlantic, Marconi came to the United States in November of 1899, and demonstrated his wireless telegraph system under the auspices of the U. S. Navy Department, and on November 2, 1899, the battleships *New York* and *Massachusetts,* equipped with Marconi apparatus, exchanged messages at a distance of 36 miles.

The *S.S. St. Paul* was the first ship of the U. S. Merchant Marine to be equipped with wireless telegraphy, and on a voyage to England, transmitted a commercial message, November 15, 1899, to a station on the Isle of Wight, thereby establishing a DX or distance record for ship-to-shore communications.

In 1901 Marconi used a kite antenna to intercept the first messages transmitted across the Atlantic. It has often been said that history repeats itself, and today we find kite antennas employed for radio communication to and from lifeboats and liferafts.

Space does not permit a detailed description of the progress made in wireless telegraph transmissions through the years. Radiotelephony, followed by the advent of broadcasting in the closing months of 1920, was made possible by the creation of the three-element vacuum tube by Dr. Lee De Forest. From this invention sprang radio facsimile and television transmissions and then the startling "static free" wide-band F-M broadcasting system invented by Major Edwin H. Armstrong, which appears destined to replace the amplitude method of broadcasting for regional and local coverage.

Just prior to World War II, the use of the radio spectrum extended to approximately 60 mc, with considerable experimentation taking place on all frequencies far up into the microwave spectrum, where the length of radio waves is measured in centimeters.

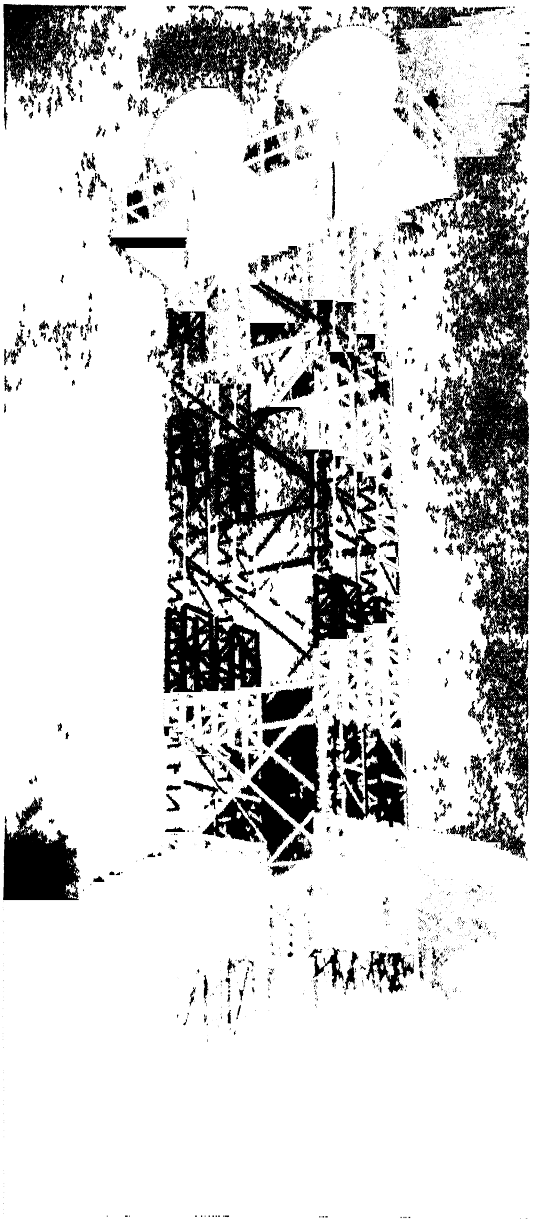


FIG. 16-1. 18-centimeter parabolic antennas employed in 1931 in microwave duplex communication link between Dover, England, and Calais, France.

A microwave duplex telephone and telegraph link was demonstrated successfully between Dover, England, and Calais, France, by the International Telephone and Telegraph Laboratories, Inc., on March 31, 1931, and was installed commercially between Lympne, England, and St. Inglevert, France, in 1931, operating on a wave length of 18 centimeters and using a parabolic antenna for transmission and reception. This microwave system required a power of only one-half watt and employed transmitting and receiving antennas only 2 inches in length. Radiation emitted and received from the antennas was concentrated into very sharp beams by means of the paraboloidal reflectors which measured 10 feet in diameter. The gain of these reflectors was in the order of 28 db at each end. Figure 16-1 shows the parabolic transmitting and receiving antennas employed in these historic transmissions.

Military necessity, during World War II, stimulated experimentation and development of tubes and equipment for use in this new spectrum, and the proximity fuse and radar were born, along with many other new applications of radio transmission to communications, navigation, ship and aircraft detection, and direction finding

From the time of Hertz, engineers and physicists like Marconi, Kennelly, Heaviside, Appleton and a host of others have been exploring the characteristics and vagaries of radio wave propagation. Today their successors are still seeking the answers to several unanswered questions, particularly regarding the behavior of waves in the very-high and microwave spectrum. Radio noise emanating from the sun has been detected both in the microwave spectrum and on lower frequencies. Considerable data have already been accumulated; predictions have been made regarding propagation conditions that may be encountered during future periods of sun spot maxima. The knowledge of radio wave propagation should progress substantially

One of the most sensational experiments in radio wave propagation occurred on January 10, 1946, when the Signal Corps staff of the Evans Signal Laboratory at Belmar, New Jersey, pierced the ionosphere and obtained the first reflection of pulse transmission from the moon. Radar pulses of one-half second duration were transmitted on a frequency of 112 mc at five-second intervals from a modified SCR-270 radar set and reflections obtained at five-second intervals. Astronomers calculate the average distance between the earth and the moon to be 238,857 miles. Figure 16-2 shows a photograph of the double radar antenna employed in this experiment. The Signal Corps engineers, under the direction of Col. John DeWitt, used an ultra-sensitive

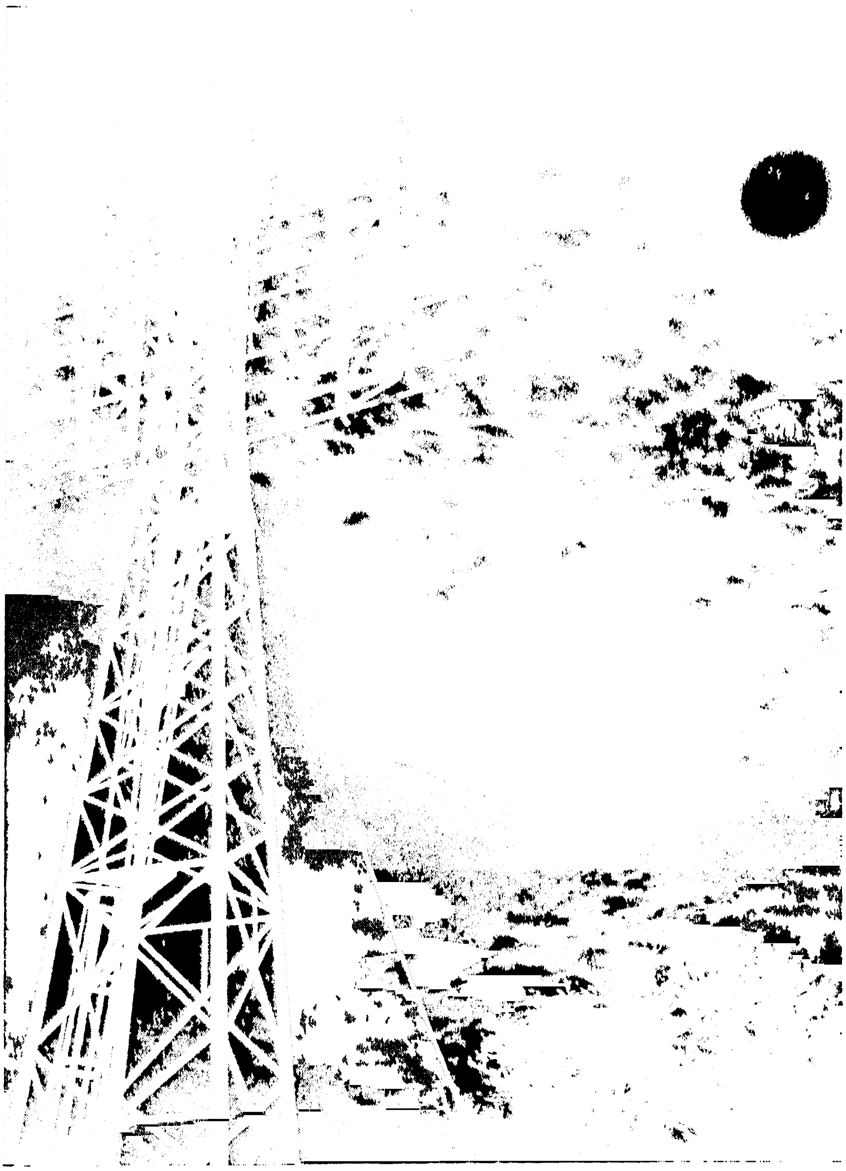


FIG. 16–2. This photograph of SCR-271 radar shows the antenna aimed at the moon. (Courtesy U S Signal Corps)

receiver to detect the faint echoes of the initial radar pulses reflected back from the moon as shown in Figure 16–3.

The observation shown was made during the rise of the moon at 11:00 P.M. on January 22, 1946, when the satellite was at an azimuth of 89° from north (approximately due east). The white scale beneath the trace of the oscilloscope beam is superimposed upon the photograph to indicate the approximate distance of the moon. On most radar oscilloscopes, this scale appears directly on the oscilloscope face.

These experiments have led radio engineers to speculate on the possibility of employing the moon as a reflecting point for the purpose of transmitting radio messages across transoceanic routes making use of microwave frequencies. The factors involved in such considerations include problems such as cosmic noise, doppler shift, and special astronomical effects. The type of communications which the moon could support as a passive repeater is dependent on the nature of its surface A moon with a smooth surface might reflect broadcasting and television signals, whereas a rough surface might limit transmissions to radiotelegraph devices only.

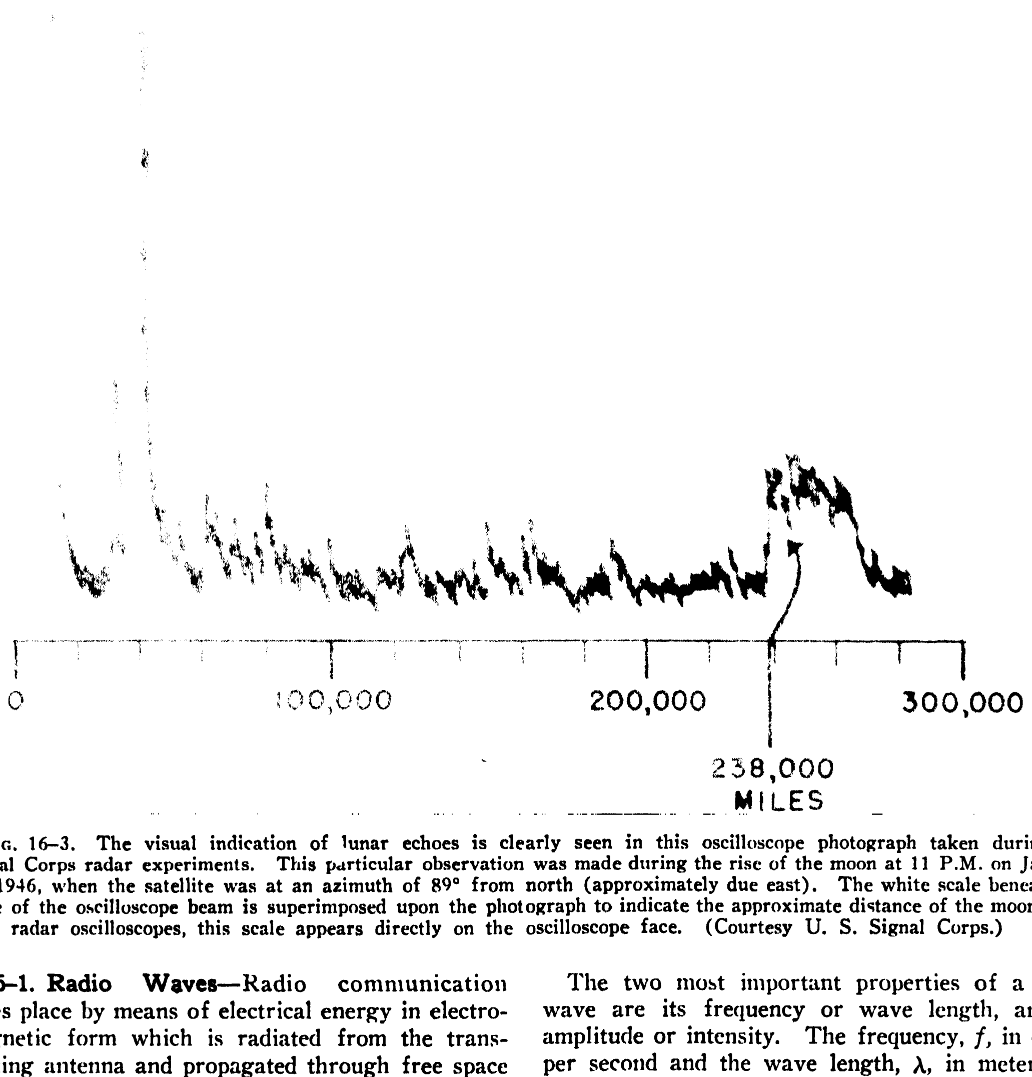


Fig. 16–3. The visual indication of lunar echoes is clearly seen in this oscilloscope photograph taken during the Signal Corps radar experiments. This particular observation was made during the rise of the moon at 11 P.M. on January 22, 1946, when the satellite was at an azimuth of 89° from north (approximately due east). The white scale beneath the trace of the oscilloscope beam is superimposed upon the photograph to indicate the approximate distance of the moon. On most radar oscilloscopes, this scale appears directly on the oscilloscope face. (Courtesy U. S. Signal Corps.)

16–1. Radio Waves—Radio communication takes place by means of electrical energy in electromagnetic form which is radiated from the transmitting antenna and propagated through free space with the velocity of light. The portion of the electromagnetic spectrum currently employed for radio work extends approximately from 10,000 cycles per second to 30,000 mc per second, electromagnetic radiations in this range being known as radio waves. Radio waves differ from other electromagnetic waves, such as light, heat, and X rays only in frequency or wave length.

Radio waves are made up of two components, an electrostatic field and a magnetic field. The total energy in the wave is equally divided between these two fields. The electrostatic and the magnetic field are at right angles to each other and are also at right angles to the direction in which the wave is moving. The direction with respect to the surface of the earth of the lines of force of the electrostatic field determines the polarization of the radio wave.

The two most important properties of a radio wave are its frequency or wave length, and its amplitude or intensity. The frequency, f, in cycles per second and the wave length, λ, in meters are related in the following manner:

$$\lambda = \frac{300{,}000{,}000}{f}$$

where 300,000,000 is the velocity of light in meters per second. The intensity, or strength, of a radio wave is expressed in terms of the unit "volts-per-meter." As this is a rather large unit, "millivolts-per-meter" and "microvolts-per-meter," abbreviated mv/m and μv/m respectively, are more commonly used in practice. The intensity of a radio wave in any of these units is an expression of the voltage stress produced in space by the electrostatic component of the wave.

16–2. Classification of Radio Frequencies—The portion of the electromagnetic spectrum presently employed in radio work extends from approximately 30,000 meters (10 kc) to one centimeter (30,000,000 kc). Propagation characteristics vary considerably throughout this large range of frequencies; therefore, in discussing propagation characteristics of radio waves, it has been found convenient to divide radio frequencies into the following classifications.

Frequency (kc)	*Designation*	*Abbreviation*
10 to 30	Very low	VLF
30 to 300	Low	LF
300 to 3,000	Medium	MF
3,000 to 30,000	High	HF
30,000 to 300,000	Very-high	VHF
300,000 to 3,000,000	Ultra-high	UHF
3,000,000 to 30,000,000	Super-high	SHF

When dealing with the higher frequencies, it is more convenient to employ the unit "megacycle" instead of the smaller unit "kilocycle." When this is done, the very-high-frequency band becomes the 30 to 300 mc band, one megacycle being equal to one million cycles. Radio waves between one meter and one centimeter (300–30,000 mc) are conveniently referred to as microwaves.

16–3. Wave Motion—Radio communication requires the propagation through space of electromagnetic waves. Before proceeding with the subject of radio wave propagation, it is essential first to consider the characteristics of wave motion. The most familiar wave motion is that of water waves. If a stone is dropped into a pond of water, wave motion is immediately produced on the surface of the water because of the impact, and waves spread out radially in all directions from the point where the stone strikes the water. The wave motion produced is caused by both pressure and tension at the surface of the water, the crest of the wave representing the pressure, and the trough, the tension. The water itself does not move forward appreciably as might be believed when watching the waves; it is the form of the wave which travels forward. Actually, the particles of water have an up-and-down movement about their position of equilibrium and, after a complete wave has passed, these water particles are in the same position they were in before the arrival of the wave.

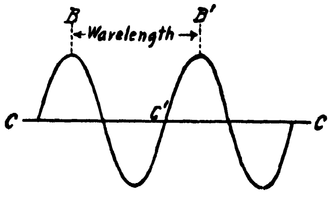


FIG. 16–4. Graphical representation of water waves.

Wave motion possesses four characteristics—namely, wave length, velocity, frequency, and amplitude. Consider the waves that are produced on the surface of a body of water, as represented in Figure 16–4. The straight line C represents the surface of the water when it is at rest. The curved line represents the surface of the water after it has been set in motion by the impact of a stone as mentioned above. One complete wave extends from C to C′ or from B to B′. This distance is called the wave length and in radio literature is symbolized λ, the Greek letter lambda. It should be noted that a wave length is the distance from any point on a wave to the corresponding point on the next wave.

Water waves are carried along by water. Water is their medium. Radio waves are propagated through space as electromagnetic waves without any recognized physical medium. As mentioned previously, an all-permeating medium known as ether has, in the past, been credited with sustaining electromagnetic waves. Light and heat waves are also electromagnetic waves and differ from radio waves only in wave length. The speed or velocity of all electromagnetic waves is the same: 186,000 miles (300,000,000 meters) per second.

There is a definite relation between the length of a wave and its velocity which will be confirmed by the following experiment. Stand on the shore and estimate the length of water waves as they pass by. Assume that the distance from crest to crest of each wave is 12 feet and the number of waves passing each second (known as frequency) is 10. What is the velocity? As each wave is 12 feet long and 10 pass each second, the velocity must be 12 × 10 or 120 feet per second. This is a general rule and can be expressed:

Velocity = number or frequency × wave length

It has already been stated that the velocity of radio waves is 300,000,000 meters per second. Substituting in the above formula, the wave length of radio waves can always be determined if the frequency is known; likewise if the wave length is known, the frequency of the waves can be determined by the following relationship:

$$f = \frac{V}{\lambda} \quad \text{or} \quad \lambda = \frac{V}{f}$$

where f = frequency in cycles per second
λ = wave length in meters
V = velocity of radio waves in meters per second

Example: What is the frequency of a radio wave if the wave length is 300 meters?

$$f = \frac{300{,}000{,}000}{300} = 1{,}000{,}000 \text{ cycles per second}$$

The frequency of 1,000,000 cycles per second in the above example is usually more conveniently expressed in kilocycles per second or megacycles per second. One kilocycle equals 1000 cycles; one megacycle equals 1,000,000 cycles. A frequency of 1,000,000 cycles per second can therefore be expressed as either 1000 kilocycles per second or one megacycle per second.

Referring again to Figure 16-4, it will be noted that the waves are divided into two parts, one above the center line, the other below it. In one part, the water has moved upward; in the other, downward. The maximum value that the wave moves upward or downward is known as the amplitude of the wave. It is the wave's amplitude that determines the amount of energy it contains.

16-3a. Damped Waves—The waves illustrated in Figure 16-5 are called damped waves. It should be noted that the waves diminish in amplitude, i.e., each succeeding cycle has a smaller amplitude than the preceding one. All the waves from S to F comprise one wave train. The following mechanical analogy will illustrate the production of a damped wave train. Hang a weight on a spring, pull the weight down and let it free. It will vibrate up and down and gradually come to rest. The moving weight will set up waves in the air which cannot be heard (sub-sonic), but these waves are of exactly the same character as the motion that produces them. The motion of the weight is gradually decreased because of friction. The waves produced in the air by the movement of the weight are exactly as shown in Figure 16-5. They are of decaying amplitude. The radio waves produced by spark transmitters formerly employed in marine service were of decaying amplitude and were therefore damped waves.

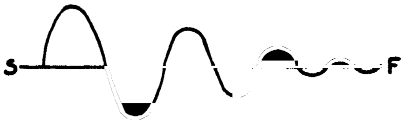


Fig. 16-5. Damped waves.

16-3b. Undamped Waves—Waves in which the amplitude remains constant are known as undamped or continuous waves (CW). The following experiment will illustrate how a wave train of constant amplitude can be produced. The same spring and weight are used for this experiment. Pull the weight down and let it free. Each time the weight reaches the uppermost position of its travel and is starting downward again, tap it just hard enough to make it go down to its first, lowest position. Do this each time it starts downward. Its motion, and hence the waves set up by it, can be represented by Figure 16-6. The amplitudes of each cycle are the same. It is an undamped wave. In order to make it undamped or continuous, it is necessary to add energy each cycle by tapping it at the proper time. Undamped radio waves are generated by supplying energy at the proper instant of each cycle. Undamped radio waves have many advantages over damped waves and, by international agreement, have replaced the latter with the one exception of emergency operation of lifeboat transmitters.

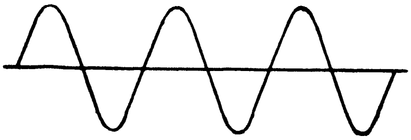


Fig. 16-6. Undamped waves.

16-4. Characteristics of Electromagnetic Waves—Electromagnetic waves are subject to reflection, refraction, and absorption, the degree of each depending upon the frequency of the wave and the material they encounter in their travel. The effects produced can best be described by considering the case of visible light waves, which like radio waves are also electromagnetic in character and have the advantage, for this discussion, of being visible.

16-4a. Reflection—When a billiard ball strikes a cushion, its direction of motion is changed. In the same way, an electromagnetic wave attempting to pass from one medium to another may be turned back at the common surface of the two media. This is illustrated in Figure 16-7 where a light wave impinges upon the surface of a mirror at an oblique angle and is turned back, or reflected. The angle of reflection is equal to the angle of incidence.

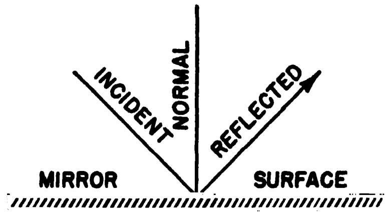


Fig. 16-7. Reflection.

16-4b. Refraction—Everyone is familiar with the effect produced when a stick is immersed in clear water and the part of the stick under water appears to bend at an angle from the part of the stick in the air. The reason for this visual distortion is that the light waves alter their direction of travel when they pass from air to water and vice versa, and the stick appears to be bent, since the waves travel at different velocities in the two media. In this particular case, the light waves travel more slowly in the water than in the air and the direction of propagation in water is bent toward the normal as shown in Figure 16-8. This is the phenomenon of refraction. The ratio of the velocity of the waves in the air above the surface of the water to the velocity of the waves in the water is the refractive index. Since the waves travel more slowly in water than in the air, the refractive index of water is greater than that of air.

The velocity of electromagnetic waves is dependent upon the electrical and magnetic properties of the media through which they travel. It is important to remember this, since it will be helpful in

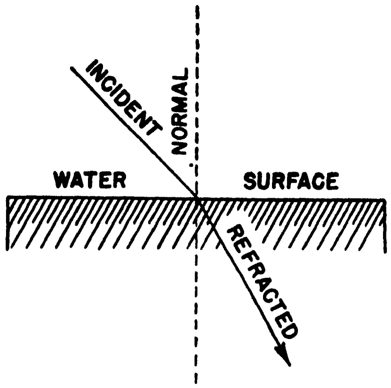


FIG. 16-8. Refraction.

understanding how radio transmission over long distances is accomplished. In air, the velocity of radio waves is 3×10^8 meters per second. The velocity in any other medium may be derived from the formula: $\frac{3 \times 10^8}{\sqrt{\mu K}}$ where μ is the permeability and K the dielectric constant of the medium.

16-4c. Dispersion—Let us examine further the change of velocity of electromagnetic waves when they pass from one medium to another. This can be done by studying the effect of passing sunlight through a glass prism. Sunlight is composed of light vibrations of many different frequencies and, consequently, appears as white light. However, when we pass these component vibrations of what appears to the eye as white light through a glass prism, the difference in frequency of the component vibrations are refracted at different angles when passing through the glass and reappear on the other side resolved into a spectrum comprising parallel colored bands of light in which red is the least, and violet the most, deviated from the angle at which the white light entered the glass. This is illustrated in Figure 16-9.

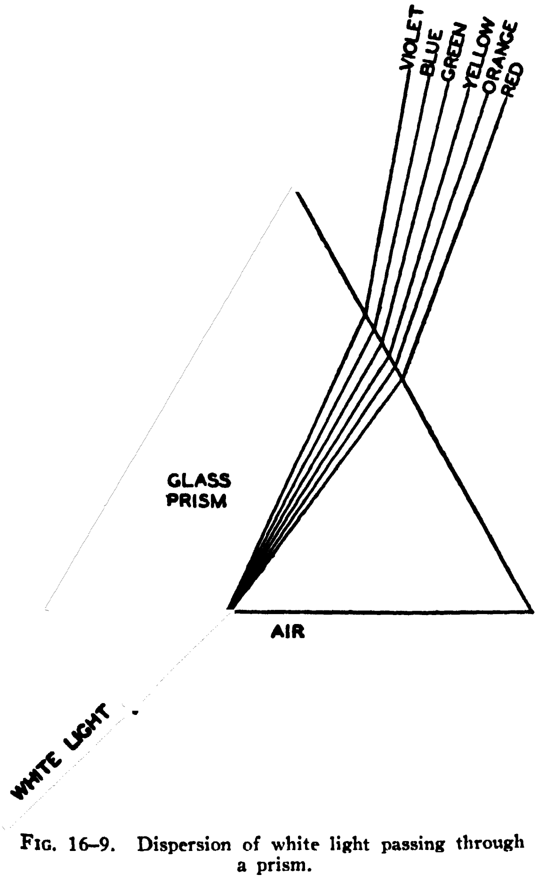


FIG. 16-9. Dispersion of white light passing through a prism.

16-4d. Total Reflection—Figure 16-8 has shown how a light wave in passing from air into water is refracted toward the normal. The reverse is true of a light wave passing from water to the air which in this case is refracted away from the normal. In every case where the velocity is less in the new medium than in the original one, the ray is bent away from the plane of the boundary surface at the point of entry.

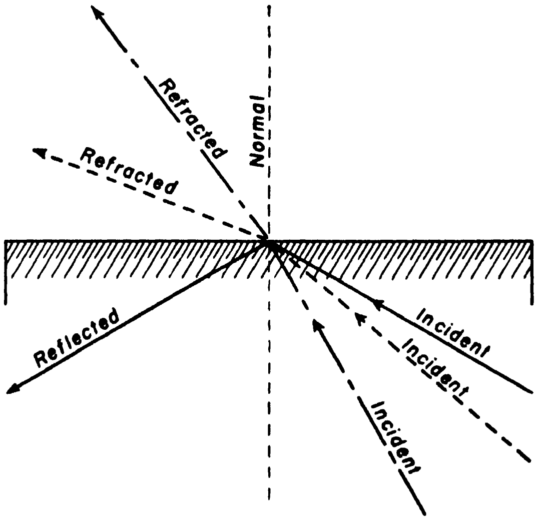


FIG. 16-10. When the angle of incidence reaches the critical angle total reflection occurs.

If the direction of the ray passing from water to air becomes more oblique to the normal, the angle made with normal by the ray in the air becomes correspondingly greater and eventually a point is reached when the ray, on emerging into the air, just grazes the common surface and is in fact at right angles to the normal. If the obliquity of the ray is still further increased, as shown in Figure 16-10, the ray does not enter the air but is totally reflected at the common surface; the angle of a reflection being equal to the angle of incidence. The angle of the incident ray to normal, when total reflection occurs, is known as the critical angle.

16–4e. Other Factors—There is still another phenomenon that is not explained by either simple reflection or refraction alone. It is a common occurrence in the propagation of radio waves over long distances resulting from the bending of a ray from a new medium back into the original one. However, before proceeding with the explanation of this phenomenon, it is necessary to consider further what takes place when an antenna is energized by a source of radio energy.

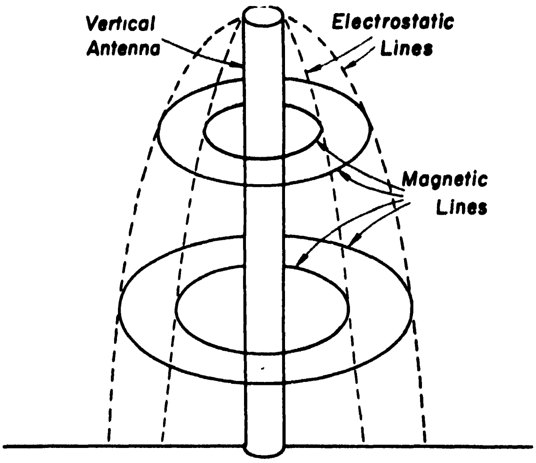


Fig. 16–11. Electrostatic and magnetic fields surrounding a grounded vertical antenna.

16–5. Radiation of Radio Waves—In order to radiate electromagnetic waves, it is necessary to excite a transmitting antenna by connecting it to a suitable source of alternating current. A 60-cycle alternator, such as produces the usual power and lighting current, would not do. To achieve radiation, it is necessary that the dimensions of the transmitting antenna approach at least a fraction of the magnitude of a wave length of the frequency to be transmitted. The radiation from a conventional antenna would be negligible at 60 cycles since a wave length at this frequency exceeds 3100 miles. Therefore, it can be seen that the frequency of the alternating current in a transmitting antenna must be high in order to radiate sufficient power to produce any effect in a distant receiving antenna. The lowest frequency employed in practice to communicate by radio waves is 13,000 cycles per second.

The radiation from a single conductor vertical antenna is illustrated in Figure 16–11. This type of antenna, which operates against ground, is known as a Marconi antenna. The conductor of this type of antenna may be considered as one side of a large electrical condenser with the ground the other side. In addition, such an antenna possesses inductance, in the form of distributed inductance along the entire length of the conductor. The current flowing in the antenna produces a magnetic field around the antenna, while the voltage on the antenna produces the electric field. These two fields combine at right angles some distance from the antenna and are propagated through free space as an electromagnetic field.

The natural, or fundamental, wave length of an antenna, which is the antenna's natural resonant frequency without any external loading, is determined by its distributed capacitance and inductance. These, in turn, are a function of the antenna's height, length, number of conductors, and geometrical shape. The resonant frequency of an antenna may be altered through the use of external condensers or inductors. A condenser connected in series with the antenna increases the frequency at which the antenna resonates. An inductor connected in series with the antenna decreases the frequency at which the antenna is resonant.

16–5a. Radiation Field—It has been shown that, when a grounded antenna is excited by a source of radio frequency, a wave motion is produced, consisting of expanding electric and magnetic fields of force spreading out from the antenna in all directions. It is important to remember that at a distance from the antenna the moving electric and magnetic fields do not exist separately but are in time phase with each other, although at right angles to each other in space. The maximum strength of the magnetic field occurs when the electric field is also at a maximum. The movement of the electric and magnetic fields above and in the surface of the earth is somewhat as portrayed in Figure 16–12. The velocity of the waves in space has been previously stated as 300,000,000 meters

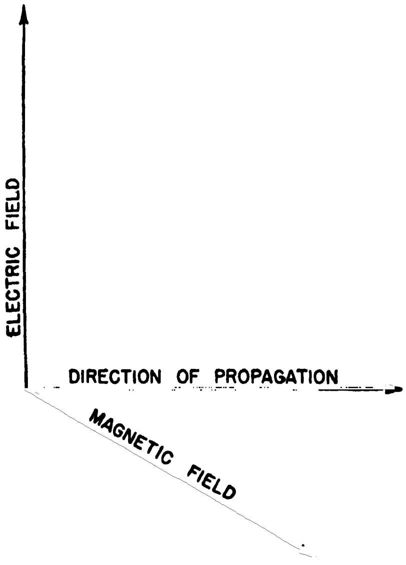


Fig. 16–12. The electric and magnetic fields of the radiated wave are at right angles to each other and are at right angles to the direction of propagation. In the above illustration the wave is vertically polarized.

(186,000 miles) per second, but the frequency of the consecutive bands of maximum and minimum electric and magnetic fields is dependent upon the frequency of the radio transmitter. The measurement of distance between any two consecutive maxima of either electric or magnetic field is the wave length of the electromagnetic wave.

The strength of the electric or magnetic field varies sinusoidally with respect to time at any given point remote from the transmitter and sinusoidally with respect to distance measured from the radiating antenna at any given instant. The measurement of the field intensity at various distances permits determining the distribution of energy in all directions and, for example, in the case of a broadcast station, determines its primary coverage. Such a measurement is one of the radiation field in which varying states of electric and magnetic stress are propagated outward from the radiating structure and represents an actual dissipation of energy. As stated previously, the two fields, electric and magnetic, comprising the radiation field, are in time phase with each other but in space quadrature (right angles) and both are at right angles to the direction of propagation, as shown in Figure 16-12. The radiation field composes the total field at a distance a few wave lengths from the antenna.

Within a few wave lengths of the transmitting antenna, the lines of both magnetic and electric force are appreciably curved, but at great distances the curvature becomes so slight that the lines become almost a vertical plane, presenting to a receiving antenna a network of horizontal and vertical lines for a normally polarized wave. The wave front is never truly vertical unless the wave is traveling in free space or is passing over a surface which has infinite conductivity. For example, the bending of the wave would be less when it travels over salt water, which has a high degree of conductivity, as compared to dry sand, which introduces losses resulting in forward tilting of the vector of electric force, producing a rotating field of elliptical form. The angle of forward tilt increases with frequency and with decreasing conductivity of the surface over which the wave is passing. The conductivity of the earth plays an important part in determining the ground wave which, in the case of a standard broadcast station, is one of the factors that determines the coverage of the station. Ground conductivity is expressed in terms of electromagnetic units (e.m.u.).

16-5b. Induction Field—When an antenna is excited by a source of radio frequency, there results, in addition to the radiation field, another field comprising a variation of electric and magnetic fields in which there is no dissipation of energy. The electric and magnetic fields in this case are in *both time and space quadrature (90° out of phase in time and at right angles to each other in space) as* compared with the electric and magnetic forces of the radiation field (which are *in phase with each other but in space quadrature*), and the energy simply oscillates from one to the other without any being lost.

In the case of the radiation field, the intensity of both the electrostatic and magnetic fields over a perfect conducting surface falls off inversely as the first power of the distance from the energizing source. In the case of the induction field, the intensity of the magnetic component of the field falls off inversely as the square of the distance while the electrostatic component falls off inversely as the cube of the distance. Due to the fact that the induction field falls off at a rate much greater than the radiation field, it is not important in the usual application of space radiation. The induction field is employed, however, in certain applications such as "remote control" without interconnecting wires, and "wireless" phonograph players.

16-5c. Field Intensities—The induction field is stronger than the radiation field within a wave length or two of the antenna and at greater distance the reverse is true. The actual strength of the two fields are proportional to $\frac{2\pi hi}{\lambda d}$ (radiation) and $\frac{hi}{d^2}$ (induction) respectively, where h is the effective height of the antenna, i the current in the antenna, and d the distance to the point of measurement; both h and d must be in the same measurement units.

At a distance where $\frac{2\pi hi}{\lambda d} = \frac{hi}{d^2}$, that is, where $d = \frac{\lambda}{2\pi}$, the intensities are equal. At a distance of a few wave lengths, the intensity of the induction field is very low and may be neglected in comparison with the latter.

Neglecting attenuation of the radiation field, its intensity can be determined from the following mathematical expression:

$$e = 120\pi \frac{ih}{\lambda d} = 377 \frac{ih}{\lambda d}$$

where e = the field intensity in millivolts per meter
i = r-f current at base of antenna in amperes
h = effective height[1] of antenna
λ = wave length in same units as h
d = distance from transmitter to point of measurement in kilometers

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[1] The current is usually not equally distributed along an antenna. *Effective height* is an expression, used chiefly in connection with grounded vertical broadcast antennas, which states the height of antenna which would be required to produce the same field intensity as the antenna under consideration, provided the current along the entire length of the antenna were uniform and equal to the current at the base of the antenna under consideration. The effective height of an antenna is somewhat lower than its physical height.

16–5d. Units of Measurement—Several different methods and types of apparatus are employed in field strength measurements. The universally adopted unit of measurement is the "volt per meter." The unit "volts per meter" is a large one; for ordinary purposes, it is more convenient to use "millivolts per meter" or "microvolts per meter."

The field intensity, expressed in volts, millivolts, or microvolts per meter, is a measure of the intensity of the signal from a radio transmitter at the point the measurement is made. It is an expression of the voltage stress produced in space by the electrostatic component of the electromagnetic wave; this voltage being equivalent to the voltage that would be induced in a conductor one meter long by the magnetic field of the radio wave. As the strength of the electrostatic and magnetic field varies sinusoidally with respect to time at any given point, the field intensity is expressed in terms of the effective value of the voltage produced by the passing wave.

The equation given in 16–5c above shows that the field intensity at a distance from the transmitting antenna is proportional to the product of the antenna current and effective antenna height. International radio regulations require the radiated power be expressed in *meter-amperes,* i.e., the effective height in meters times the antenna current.

16–6. Polarization—Radio waves may be propagated either vertically or horizontally polarized, depending upon the physical arrangement of the radiating system. A demonstration of polarized waves can be made by watching the waves that travel down a piece of rope, one end of which is free and the other end held in the hand. If an up and down motion is imparted to the rope, the waves will move along the rope in an upward and downward direction and are vertically polarized. Sea waves are a form of vertically polarized waves. If the motion imparted to the rope is in a horizontal side-to-side direction, the waves in the rope will be horizontally polarized.

An oblique transverse motion given to the end of the rope in a straight line making, say, an angle of 45° with the vertical, would produce obliquely polarized waves. Such waves in all three cases are called *plane polarized* waves and that is the name given to any system of transverse wave motion which takes place in one plane only through the direction of propagation, no matter whether the plane be vertical, horizontal, or in any intermediate direction.

An electromagnetic wave radiated by a vertical antenna is vertically polarized, since its electric field is in the vertical plane through the direction of travel, even though the magnetic lines of force move in a horizontal plane. All references to polarization of a wave in subsequent paragraphs will be in reference to the plane of the electrical field.

16–6a. Abnormally Polarized Waves—Consider the case of an antenna which is neither vertical nor horizontal but is sloping at some acute angle to the earth's surface, as for example the trailing antenna from an aircraft. This results in tilted circles of magnetic force surrounding the antenna, and the electric field is no longer perpendicular to the earth's surface when the wave front reaches a receiving antenna on the earth. Such a wave is still polarized, but its plane of polarization may make an angle as high as 60° with the vertical plane through the direction of travel. Such a wave is said to be abnormally polarized.

16–6b. Elliptically and Circularly Polarized Waves—In radio direction finding, difficulties are encountered in securing an accurate bearing on a transmitting station when the radio wave has a complex polarization either in the form of circular or elliptical polarization.

Circular polarization occurs when the vertical component is at its maximum amplitude when the horizontal component is zero, and vice versa. During one cycle, the wave takes up in turn every plane of polarization while remaining at constant amplitude, although its electric and magnetic fields in any one plane rise and fall sinusoidally. The direction of rotation may be either to the right or to the left. Using the rope analogy, a circularly polarized wave would be produced by a rapid rotary movement of its free end either in a clockwise or counterclockwise direction.

Should the horizontal component of the wave have a smaller amplitude than the vertical one, the resultant would no longer be circular, but elliptical. Elliptically polarized waves also result when the two components of the wave are not in quadrature but bear some random phase relation.

16–7. Attenuation—At a distance a few wave lengths from the antenna, the field instead of falling off inversely proportional to the distance falls off faster, depending upon the type of surface over which the waves are propagated. The falling off, or attenuation, of the field is greater over ground than over sea water. The attenuation over sandy soil is much greater than over salt marshland. Furthermore, the higher the frequency of the waves, the greater are the losses and, consequently, the higher the attenuation. Hence it is easy to see that the field strength of the waves radiated along the ground from a standard broadcast station will be greater than the field strength of the waves radiated from a police radio station of the same power and measured at the same distance, since broadcasting stations operate on frequencies lower than those assigned to the police service. In fact, the primary service area of a standard broadcasting station operating on the lower frequency portion of the band 550–1600 kc is considerably greater than that of another station operating on the high end of the band, assuming each has the same power and antenna efficiency.

16–8. Ground Wave—The electromagnetic wave which travels along the surface of the earth or water is referred to as the ground wave. Reception of the ground wave is possible over considerable distance in the frequency range from 13 kc to 1600 kc since the electromagnetic waves follow the curvature of the earth as the result of diffraction, which is the property that makes it possible for light waves to bend around corners to a slight extent. Since radio waves are lower in frequency, the effect is more pronounced.

The ground wave radiated from a single vertical antenna is distributed equally in all directions. If the waves do not encounter any obstacles in their path, the energy measured at any radius from the antenna will be the same, provided the attenuation is uniform. However, should a high building or hill be encountered in the path of the waves, the field on the side away from the antenna might be so low as to be indiscernible. The electromagnetic field of the waves is deflected around the obstacle, causing a screening or shadowing effect. Bridges or other similar obstacles produce the same effect. Some of the energy in that portion of the waves which are deflected by the obstacle is deflected back toward the direction of propagation and reception is restored in some measure. In any event, energy is dissipated in the obstacle and the field will be less than it would have been had no obstacle been encountered. The effects of shadows with regard to television and other services operating in the very-high-frequency bands is discussed in more detail later in this chapter.

16–9. The Sky Wave—It has been previously mentioned that electromagnetic waves are of the same nature as light waves. They follow the curvature of the earth and thus make radio reception over great distances possible.

Even when this effect is taken into consideration, it is inadequate to account for the reception of signals at hundreds of miles from the transmitter and the variation of the strength of these signals during day and night winter and summer. In order to explain such phenomena, it is necessary to consider that all the energy from an antenna is not radiated along the ground but some is radiated at various angles above the horizontal and travel into the electrically conducting ionized layers in the ionosphere, where it is reflected back to earth at various distances from the transmitter. Radio signals received over such paths are often referred to as sky wave signals. The height and degree of ionization of the layers, as well as the frequency employed, determine how far the radio waves travel. There are many variations in the height and in the degree of ionization of the reflecting layers and, therefore, the effect of these layers on radio transmission varies with time of day, with season, and from year to year. Other outer shells of the earth's atmosphere such as the troposphere bend radio waves beyond the horizon as will be shown later in this chapter.

16–10. The Ionosphere—In the regions above the earth, the air particles are more widely scattered than they are in the lower atmosphere close to the earth and, consequently, when the ultraviolet radiation from the sun bombards the molecules composing these air particles, they become ionized, i.e., there are produced free electrons and positive ions. Since at great heights the air particles are widely scattered, there are less collisions and, consequently, less recombination of electrons and positive ions; hence this region remains ionized for a considerable time. The region in which the ionization is great enough to affect radio wave transmission lies between 30 and 250 miles (50 and 400 kilometers) above the earth's surface. This region is called the ionosphere. (See Figure 16–13.) The effects of the ionosphere on radio waves were first observed in this country by Kennelly and in England by Heaviside. Consequently, this region is often referred to as the Kennelly-Heaviside layer. The word "layer," however, is rather misleading, since the region has no sharp boundaries. The ionization in the ionosphere is not uniformily distributed with altitude but is stratified, and there are certain definite layers in which the ionization density is suffi-

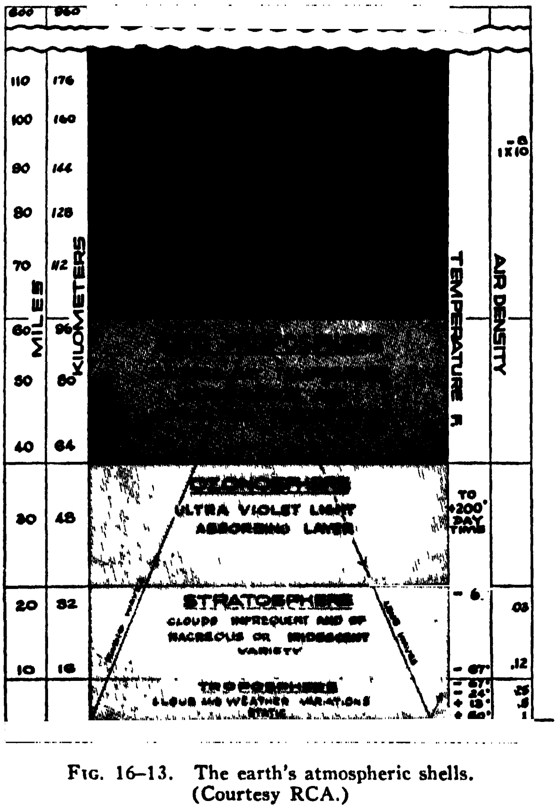

FIG. 16–13. The earth's atmospheric shells. (Courtesy RCA.)

cient to reflect radio waves. The height and ionization density of these layers is not constant but varies with the time of day, from season to season, and as a function of the 11 year cycle of sunspot activity.

Subsequent to the discovery of the Kennelly-Heaviside layer, other layers were identified by Professor E. V. Appleton. The first layer, identified as the *E* layer, exists at a height of about 90 to 140 kilometers above the earth, while the second layer, which exists as a single layer at night, is termed the *F* layer. During the day, the *F* layer divides into two separate layers which are identified as F_1 and F_2 layers. The night *F* layer exists at a height of approximately 180 to 400 kilometers. During the day, the F_1 layer exists at a height of about 140 to 250 kilometers, and the F_2 layer at a height of 250 to 350 or more kilometers in the summer, and about 150 to 300 kilometers in the winter.

A fourth layer, defined as the *D* layer, exists at times during the day at a height of about 50 to 90 kilometers.

16–10a. Bending of Wave Front in the Layer— The principal ionospheric characteristics which determine the distance at which radio transmission over long distance is possible are the height and the degree of ionization of the layers. The ionization of a layer is not uniform but increases with height and consequently the phase velocity of the waves also increases in a gradual manner as the waves penetrate into the layer. Accordingly, the effect of the ionized layer is to cause a gradual bending of the direction of the wave and may be sufficient to cause it to bend until it is traveling parallel to the earth's surface, and eventually to direct it downwards so that it again returns to the earth at a distance from the transmitter.

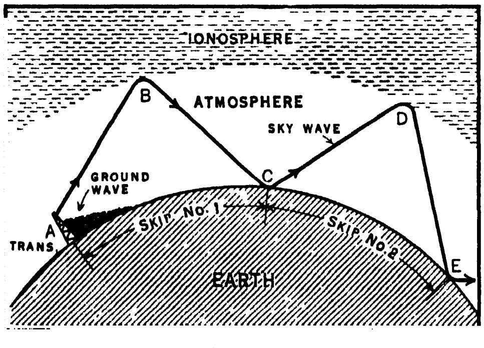

Fig. 16–14. Transmission to a distant point often takes place by means of multiple reflections. The sky wave shown above is reaching point E in two hops.

As the wave front enters the layer the upper portion of the wave penetrates deeper into the layer than the lower portion and, since the density of the layer is greater towards the center than at the lower limits, the velocity of the upper part of the wave is accelerated more than the lower part, resulting in the wave being gradually bent over and, subsequently, out of the layer back to earth.

The possibility of a wave being returned to earth depends upon the frequency of the wave and the angle at which it enters the layer. An antenna may radiate at many angles from the horizontal, and consequently, the waves may penetrate into the ionosphere at many different points and with different angles of incidence, resulting in the reflected wave spreading over a large zone on the earth's surface. Moreover, the reflected wave may be turned back to the layer from the earth as in Figure 16–14. Such multiple reflections account for the long distances over which high-frequency radio communication is possible. Transmissions may take place over a long distance as the result of multiple hops, none of which strike the earth, as explained in the footnote below.

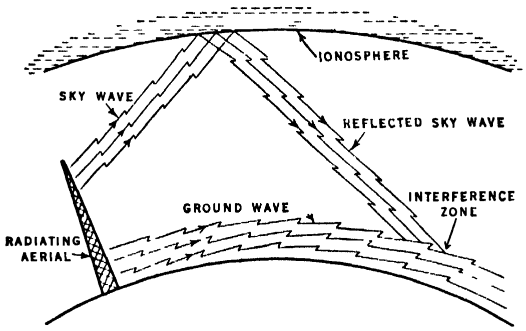

Fig. 16–15. Sky wave of low frequency reflected from ionosphere back into ground wave range of station.

The excursion of a radio wave from the earth to the ionosphere and back to earth is called a hop. Many waves make double and multihops. The number of hops is called the order of reflection.*

16–10b. Skip Distance—If one were to monitor continuously the signal from a high-frequency transmitter while traveling directly away from the transmitting antenna, the signal would decrease rapidly with distance and at a certain distance from the antenna the signal would no longer be audible. This point represents the end of the ground wave, but if one were to keep on traveling for a distance of several hundred miles, the signal would again be heard with considerable strength but with varying intensity. The area where the signal is again heard represents the zone of the first reflection from the ionosphere. The distance from the transmitter to the point where the sky wave signal comes back to earth by reflection is termed skip distance. It is defined as the minimum distance at which radio waves of a specified frequency can be transmitted at a specified time by means of reflection from the ionosphere. Reflected waves are frequently received at smaller distances by sporadic and scattered reflections.

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* It was one time believed that in the case of multiple hops that failure of propagation at any one of the ionosphere reflection points would cause failure of propagation altogether. However, it has been observed that propagation does not fail in many cases until the ionosphere at "control points," from each end of the path, fail to support the transmission. This results from the radio wave exciting scatter sources in the E layer while the wave is traveling to the F layer and on its way down after being reflected. A detailed discussion of "control points" and "short" and "long" scatter are beyond the scope of this text. See National Bureau of Standards Circular 462 for full explanation.

In the case of stations operating on lower frequencies, such as in the broadcast and police bands (550 to 2500 kc), the sky wave returns to earth within the outer limits of the ground wave and the resulting interference results in limiting the primary coverage of the station. This is shown graphically in Figure 16–15. The presence of the sky wave within the ground wave range is made evident by fading and occasional distortion of the signal. The effect is more pronounced during the dark hours, since during the daylight hours the E layer, at standard broadcast frequencies (550 to 1600 kc) is so heavily ionized that most of the energy in the sky wave is absorbed. After dark, a de-ionizing process takes place and the layer is of the correct density to cause reflection.

16–10c. Maximum Usable Frequency, Critical Frequency—The higher the frequency of the radio wave, the less is the bending of the wave in the ionosphere. Some waves of quite high frequency completely penetrate the layer and do not return to earth. The reflected wave of high frequency, owing to its lesser degree of bending, returns to earth at a greater distance from the transmitter than a wave of lower frequency. There is also a limiting frequency; the wave highest in frequency which is bent back but in such a direction that it misses the earth's surface and returns into the layer, continuing on its way until is is completely dissipated. The highest frequency that returns to earth over a given path is the "maximum usable frequency." The highest frequency that is returned to earth from a wave striking the ionsphere at vertical incidence is the "critical frequency" for the layer under consideration.

Lowest Useful High Frequency. The strength of a radio wave decreases as the distance from the transmitter is increased, due to absorption of the energy in the wave and the spreading out of the wave with distance. Eventually a point is reached for a given frequency and power when the energy is too weak to render satisfactory service. This distance is known as the distance range of the transmitter for the particular frequency in use. Since the absorption of radio waves in the ionosphere is greater, the lower the frequency, sky waves of a frequency lower than one that is just capable of producing satisfactory service will either render unsatisfactory service or not be heard at all. The lowest frequency capable of producing satisfactory service is termed the *lowest useful high frequency.*

16–10d. Scattering—In the foregoing discussion, mention has been made of a zone lying between the end of the ground wave and the point where the sky wave first returns to earth. This is a zone in which no signal is heard. However, even though the signal cannot be heard in this zone, a very small amount of the radio waves energy is present, but it is usually completely masked by noise and far below the sensitivity of detection devices. Some of the radiations from the antenna, instead of being gradually bent back to earth from the ionosphere, are reflected downward at various angles from the regions of reflection in the layer, producing an effect known as scattering. The signal energy from scattering is sometimes sufficient to make reception possible in the skip-distance zone, but in general is weak and irregular. This phenomenon, in the case of light waves from the sun, accounts for the blue color of the sky in daytime. If the earth possessed no atmosphere, the only sunlight waves reaching it would be directly from the direction of the sun, and the sun would appear as a bright disc in a black sky. However, since the sunlight is scattered in the atmosphere, it appears to reach the earth from all directions, resulting in the familiar blue color of the sky.

Scattering sometimes occurs when a reflected sky wave strikes the earth and the energy is again propagated in all directions as from a transmitting antenna.

16–10e. DF Bearing Errors Caused by Scattering—The strength of scattered signals is uncertain. Moreover, the bearing of the transmitter as determined by a high-frequency direction finder will be much in error when scattering is present, if a bearing can be determined at all. Generally, no well-defined null can be obtained on a direction finder employing an aural null system, and the pattern on a cathode-ray indicator of a visual direction finding system will be distorted and transient in nature.

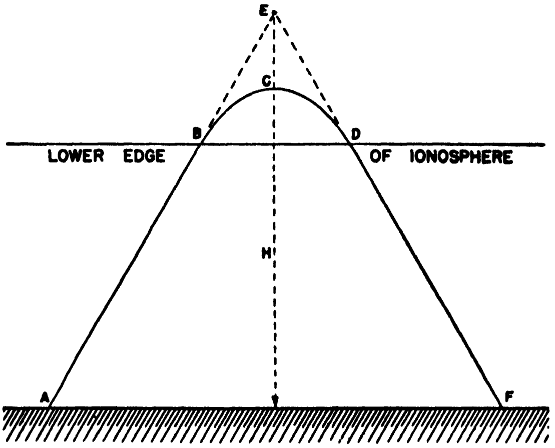

Fig. 16–16. Determination of virtual height of layer.

16–10f. Ionospheric Measurements—An analysis of the recordings of radio signals reflected from the ionosphere permits determination of the number of layers, the height of the individual layers, their density, and many other important factors that influence radio wave propagation. For example, the virtual height of a layer is measured by transmitting a radio signal from point A in Figure 16–16 to a point F. In this case, both the ground wave and the sky wave are recorded and the difference in time of arrival measured. Since the time differences are mere thousandths of a second, the signal is a very short pulse. In this case, the difference between the distance (AE + EF) and AF is found by multiplying the measured time difference by the velocity of the signal. From this, and the known distance. AF, the virtual height, H, is calculated. In practice, measuring equipment is calibrated directly in kilometers virtual height rather than time differences. Measurement of the critical frequency is determined by sending radio signals to the ionosphere at vertical or nearly vertical angles in the manner described above, repeating the determination at increasing frequencies until the signals are no longer received back from the layer. The highest frequency at which waves sent vertically upward are received back from the layer is the critical frequency of that layer. The critical frequencies vary diurnally, by season, and year to year with sunspot cycles.

From these determinations at any given time, it is possible to calculate the upper limit of radio frequency that can be transmitted over any distance and, conversely, the minimum distance for any frequency. The calculated values of maximum usable frequency are found to agree with direct observations of radio transmission over such distances. The best frequencies to use are slightly less than the maximum usable frequency.

The U. S. Bureau of Standards issues monthly reports on the conditions of the ionosphere, which includes average data for the month on the virtual heights and critical frequencies of the ionosphere layers, variation and other data, including minimum and maximum phases of the sunspot cycle. Special reports are also issued, advising of ionosphere storms and sudden disturbances which at times are of such intensity as to paralyze radio communication on high frequencies. These periods are referred to as "fade-outs" or "drop-outs."

16–10g. Absorption—Radio waves, when passing through the ionosphere, start ions in motion. These moving ions collide with the air molecules and dissipate the energy they contain. This absorption of the energy from a radio wave is an important factor in limiting radio transmission. The energy absorbed from a radio wave is greater the deeper the penetration of the waves into the ionized layer and the greater the density of ions and air molecules in the layer. Higher frequencies are less affected by absorption than are lower frequencies, for waves passing through the same layers. Absorption or attenuation of a wave is especially great in the day time and occurs mainly in the lower layers, such as the D and E layers. Much of this low-layer absorption disappears with the decrease of low-layer ionization at night.

16–10h. Absorption in the Auroral Zones—North of latitude 50° there exists the auroral zone where visible aurora is most prevalent. In these regions, abnormally high absorption of radio wave energy takes place. Radio waves passing through the auroral zones are characterized by lower signal intensity and more fluctuations than signals passing through other paths. The absorption of radio-wave energy is very great, especially during the daylight hours in these zones.

During periods of severe and prolonged ionosphere storms, which occur frequently, increased absorption occurs and a drop in the ionization of the higher layers of the ionosphere takes place. Consequently, the lowest useful high frequency is raised and the maximum usable frequency lowered, the net result being a narrowing or complete disappearance of the band of useful frequencies. It is not unusual for long distance transmissions to be impossible on all high frequencies for a day or more at a time, and to be erratic and only partially recovered in a small portion of the frequency spectrum for as much as a week. Observation indicates that the northern band of severe radio-wave energy absorption is a relatively sharp one, centered slightly to the south of the northern line of maximum auroral activity. Radio waves passing outside of this band are affected to a much smaller extent by this absorption.

It has been observed that some paths which are similar except for direction, seem to display different propagation characteristics. For example, in parts of Greenland the European high-frequency stations on about 9 to 15 mc are heard much better than United States stations at similar distances and frequencies. Also, while transmission across the auroral zone between the United States and Greenland is unfavorable for the standard broadcast frequencies (550 to 1600 kc), United States stations on these frequencies are received well in northern Canada and Greenland during the winter night. Not enough is yet known about the auroral zone to explain such effects fully.

16–10i. Fade-outs—Mention has been made of radio fade-outs during which communication circuits over certain parts of the world are disrupted due to sudden ionospheric disturbances. The generally accepted theory is that solar flares from the sun set up radiations that pierce the normal layers of the ionosphere and that these penetrations create temporary absorption regions in the normal path of the radio wave. The temporary absorption may produce a complete or partial fade-out, depending upon the solar eruption. When the flash subsides, the abnormal absorption disappears and the circuits are restored to normal. During the period of such storms, communications can frequently be maintained by lowering the frequency. These storms are most severe in the auroral latitudes and decrease in intensity as the equator is approached.

16-10j. Fading—When observing the characteristics of the ground-wave signal of a radio station either aurally or by means of a field intensity meter, the signal intensity will be observed to be quite stable until the outer limits of the ground wave are reached. At this point, the signal may become quite unstable, fluctuating up and down in intensity. The fluctuations may be rapid and may appear in almost recurrent cycles. This phenomenon is known as fading and is especially noticeable at night on frequencies extending from 500 to 2000 kc and at distances in the order of a few tens to several hundreds of miles from the transmitter.

Fading at the outer limits of the ground wave of standard broadcast stations is caused by a signal combination of the steady ground wave and the reflected sky wave from the ionosphere, with the voltages varying in and out of phase. When the sky-wave signal is opposite in phase to the ground-wave signal, voltage reduction of the signal strength occurs and the magnitude of the resulting signal is dependent upon the relative magnitude of the sky wave and the ground-wave signals. If the two signals are of the same intensity and 180° out of phase, complete cancellation of the ground-wave signal occurs. When in phase, the resultant signal is twice the intensity of the ground-wave signal. In the case of modulated waves, such as the signal from a standard broadcast station, selective fading usually occurs. In this case, the carrier and the sidebands both experience fading effects, but due to the difference in frequency, the degree of fading is different for the carrier and for each frequency in the sidebands. This results in brief periods of badly distorted reception, similar to that experienced from extreme overmodulation.

In the case of sky waves, two or more waves entering the layer at different angles may be refracted in such a manner that they eventually arrive at the same point of reception. Owing to their varying phase relationship, they produce a similar effect to that described above on the total signal intensity. If the two waves are in phase, the signal intensity increases; if in phase opposition, downward fading occurs. Lateral deviation of a signal from the normal path may also cause fading.

Many devices have been resorted to for the purpose of overcoming fading, for example, automatic volume control circuits and diversity reception. Diversity reception is accomplished by arranging receiving antennas in such a manner that the signals of two or more antennas, one of which for a moment may be receiving little energy and another considerable energy, are fed into a common receiver system which electronically selects the antenna receiving the strongest signal.

16-11. Interference—Interference to radio reception falls into two classifications, namely, atmospheric and man-made. Broadcast listeners are prone to call all forms of interference "static." Atmospheric interference is rightfully termed static and results from the discharge of electrons in the form of lightning between clouds or between clouds and the earth. Man-made interference originates from many sources involving the use of electrical apparatus and machinery. Whenever an electrical circuit is interrupted or closed, as, for example, by the commutator of a motor, relay, thermostat, or telephone dial, an electrical discharge occurs and causes the radiation of electromagnetic waves having no well defined wave length. They are of the damped-wave type already mentioned. Damped waves radiated by the ignition system of an automobile as the result of the discharge across the spark plugs produce a wide band of interference at frequencies from 13 to 100 mc.

Man-made interference also originates from devices that generate radio frequency currents as, for example, diathermy machines and radio-frequency furnaces. The radiation of interfering signals in these cases is incidental to the primary function of the equipment. However, the effects are serious, as appreciable energy may be radiated. The radiation from diathermy machines and radio-frequency heaters on high frequencies in many cases may cause serious interference to radio services over great distances.

The elimination or suppression of interference requires special treatment according to the nature of the case. Sometimes relief can be secured by resorting to special receiving antennas, by shielding the offending device, or by the application of filters to the power lines supplying power to the apparatus.

"Precipitation static" is a term used to designate a form of interference often experienced by a ship or aircraft moving through rain, hail, or dust clouds. In the case of aircraft, it charges the body of the ship, and corona [2] discharge breaks out at a sharp point, causing interference. It is eliminated by dissipating the charge on the plane through a resistance of approximately 100,000 ohms made in the form of a five-foot length of graphite-impregnated rubber-covered rope trailing from the craft.

Since the static originating from corona has a much stronger electrostatic than electromagnetic field, the use of an electrostatically shielded loop for reception will discriminate against the electrostatic field and respond to the magnetic field, thereby minimizing the interference.

16-12. Propagation of Very High Frequencies and Microwaves—Thus far in this chapter, discussion in general has been confined to radio waves that travel horizontal to the earth such as ground waves and radio waves that are radiated at various angles above the horizontal from an antenna and are reflected from the ionosphere at various distances from the transmitter as sky waves. The frequency of the waves involved in these discussions extends from 13 kc to approximately 50,000 kc.

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[2] When extremely high voltages exist in an electrical conductor, the air surrounding the conductor becomes ionized. When the voltage gradient on the surface of the conductor exceeds a certain value, an electrical discharge in the form of a glow of colored light takes place. This is known as *corona*.

We now discuss the propagation characteristics of very high frequencies and microwaves, the useful range of which is limited to the optical path or a few miles beyond the first horizon. It will be shown that under certain conditions the reception of very-high-frequency waves may take place hundreds of miles beyond the optical range.

16–12a. Optical Path—Since the ionospheric layers do not reflect the frequencies above 50 mc, except under unusual conditions and periods of uncertain duration, the utility of these waves is confined to their optical path range, usually referred to as the "line-of-sight" path of transmission. The optical path, or the distance an object may be seen in terms of its height from a point on the earth, can be calculated from the equation:

$$d = 1.23\sqrt{h}$$

where d = distance in statute miles between point and object

h = height of object in feet

The distance from the top of the object to the farthest point on the earth that can be seen is referred to as the horizon.

Due to refraction (paragraph 16–4b) there is a tendency for very-high-frequency radio waves to be bent slightly back towards the earth. This has the effect of extending the distance that the radio wave can be transmitted beyond the optical horizon (see paragraph 16–12d). The above equation, corrected for refraction, and applicable to very-high-frequency radio waves becomes $d = 1.41\sqrt{h}$. If the receiving antenna is also at an elevation, the same equation may be applied to determine the horizon for the receiving antenna; this added to the horizon for the transmitting antenna gives the maximum distance over which very-high-frequency communication can be accomplished for the transmitting and receiving antennas involved.

16–12b. Surface Wave and Space Wave—It can be shown that the received signal over the optical range is the resultant of a direct ray and a ray reflected from the ground as shown in Figure 16–17.

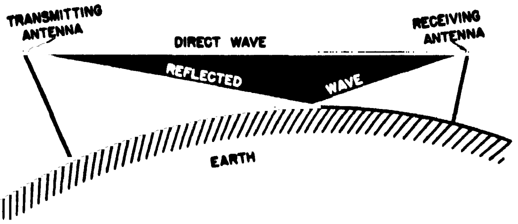

Fig. 16–17. Diagram showing both the direct and ground reflected paths by means of which energy may travel from transmitting to receiving antennas.

In most cases, the reflected ray impinges upon the ground at nearly grazing incidence and is usually reflected at high efficiency with a 180° phase reversal. Consequently, the direct ray and the reflected ray arrive at the receiving antenna at equal intensity and out of phase. The actual phase difference between the two rays depends upon the height of the transmitting and receiving antenna and the nature of the intervening ground. The direct wave and ground-reflected wave do not include any portion of the wave reflected from anything other than the ground. It is, therefore, exclusive of ionospheric and tropospheric waves.

In general, the surface or ground wave is a negligible component at these frequencies. At lower frequencies, the surface wave plays the dominant role and is responsible, for example, for all of the primary service which is furnished by stations operating in the standard broadcast band between 550 and 1600 kc. The fact that space waves rather than surface waves play the dominant role at very high frequencies is responsible for the marked difference in the characteristics of their propagation as compared to those at lower frequencies.

16–12c. Components of Radiation—In general, irrespective of the frequency, there will be three identifiable components in the radiation field of a high-frequency antenna—namely, the *direct wave*, the *ground-reflected* wave, and the *surface wave*. The direct wave is the wave traveling directly between the transmitting and receiving antennas so far above the earth that the ground no longer affects the transmission; as, for example, in transmission from one aircraft to another. The ground-reflected wave is the wave reflected at the ground before reaching the receiving antenna, as shown in Figure 16–17. The combination of the direct and ground-reflected waves is called the *space wave*.

The intensity of the ground-reflected wave may be measured by varying the height of the receiving antenna and measuring the variations in the intensity of the space waves, which are caused by the interference between the direct and the ground-reflected waves. The interference of the two waves produces maxima and minima values in the field intensity, since the direct and ground-reflected waves at certain distances are in phase and thus produce the maxima values; at other distances, they are out of phase and would cancel each other completely, except for the fact that the ground-reflected wave is weaker since it has traveled a greater distance and has in addition suffered some loss in energy on reflection from the ground.

The surface wave may be separately measured by placing both the receiving and the transmitting antennas at the earth's surface. When this is done, the space wave drops out because the direct and ground-reflected waves have an equal intensity and differ in phase by 180° (the ground-reflected wave suffers a 180° phase change and no loss in energy on reflection at the ground *at grazing incidence,* irrespective of the polarization or frequency). If we raise the receiving or transmitting antenna, or both, above the surface of the earth, the following effects will be observed. Initially there will be no change in field intensity, but as the antenna is raised a sufficient number of wave lengths above the earth (the height required depending on the frequency, ground constants and polarization), the field intensity will begin to change. The theory shows that the surface wave is the dominant component of the received field in this initial range of heights where the field is constant.

As the antennas are raised higher, the field intensity may decrease slightly and then begin increasing in direct proportion to the height, or it may increase continuously from its surface-wave value upwards; these variations at intermediate heights are also dependent on the frequency, ground constants, and polarization, and are caused by an interference between the surface and space waves, the latter no longer having a zero intensity when the antennas are raised far enough above the earth. Finally, as the antennas are raised many wave lengths above the earth (which is not feasible in the standard broadcast band), the surface wave decreases in intensity while the space wave increases in intensity and soon becomes the dominant component of the received field. Thus, excellent coverage at the ultra-high frequencies results from raising the antennas many wave lengths above the earth so as to utilize the space wave.

16–12d. Ground-wave Propagation Beyond the Horizon—The space waves do not stop abruptly at the horizon but extend a fractional distance beyond the optical path. This can be explained by the optical concept of atmospheric refraction, one effect of which is to prolong the sunset. The effect of refraction in bending the waves back to earth beyond the horizon is equivalent to that which would be obtained if the radius of the earth were increased by about 33 per cent or, we may say, 4/3 horizon is obtained because of refraction.

We have already learned that the velocity of electromagnetic waves is changed when they pass from a media of one dielectric constant into another media of different dielectric constant. In the case of the very-high-frequency waves, the physical picture to be assumed is one in which the dielectric constant of the atmosphere decreases with height above sea level. The phase velocity of the wave in this medium becomes greater as the distance from the center of the earth increases. In the case of very-high-frequency waves, we are considering waves traveling in a substantially horizontal direction. The wave front, therefore, lies in a plane which is nearly vertical, and since the upper portions travel faster than the lower, there is a tendency for the ray to bend slowly back toward the earth. This phenomenon, in its general aspects, is the same as that which is commonly assumed to explain the bending of longer waves about the earth, but in this case, we are concerned with that region of the atmosphere below one kilometer or so, where the ionization is negligible. Since the conditions in the atmosphere vary from time to time, the degree of refraction changes and, consequently, the intensity of the signal beyond the horizon changes also.

16–12e. Multipath Transmissions—Hertz, in his early experiments, proved that radio signals could be reflected from various objects. Engineers and physicists have made use of this phenomenon for many purposes, including ionospheric soundings and radar. In the very-high-frequency and microwave spectrum, signals are reflected from buildings and natural objects, and even aircraft in flight reflect radio signals from their surface in such a way that a receiving antenna may be energized as the result of signals received over more than one path. The coefficient of a reflecting surface is approximately the same at all frequencies (particularly in the range of 50 to 1000 mc); as the frequency is increased, multipath reflections will occur from smaller objects. The amount of energy reflected is proportional to the area presented to the wave front; consequently, reflections from small objects will be weaker. When the receiving antenna is in a shadow area, that is, where no signal of appreciable magnitude is received from a transmitter over a direct path, energy from a reflecting surface may be sufficient to furnish F-M and television service. However, it is important to remember that in such an instance multipath reflections may have such phase and amplitude relationship as to produce distortion in the received signal. This is particularly true in the case of television, since it may result in the reception of several images simultaneously, but not in the proper phase relation. This effect is discussed at greater length in the case of television service in Chapter 12.

16–12f. Effects of Terrain—Dr. Kenneth Norton, in an F.C.C. hearing regarding the allocation of frequencies to the F-M broadcasting service, once stated that it was necessary to consider the gross effects of terrain when investigating the expected field intensity at a particular receiving location or along a particular radial, pointing out that comparatively small systematic deviations in the terrain can cause relatively large variations in the expected ground wave field intensity at points well beyond the line of sight. He also stated that it is believed that smaller irregularities cause the ground wave, as it travels along, to break up into a multiplicity of paths, and that these waves recombine at any given receiving point into the resultant field at that point. He explained, "Quite often ground-wave field intensity measurements are made along city streets, with the transmitting antenna located only a little above the tops of the buildings, and of course, these measured fields fail to agree with the theoretical values calculated on the assumption that the transmitting antenna has an effective height equal to its height above the street. In this case, the effective height of the transmitting antenna will be only slightly more than the height above the tops of the buildings."

16–12g. Troposphere Propagation of Very High Frequencies—Under certain conditions of the atmosphere, very high frequencies are capable of transmission over distances of several horizons. For the explanation of the physics of such transmission, we must consider another of the earth's shells that lies directly above the earth and is known as the troposphere (see Figure 16–13).

The troposphere extends up to about 10 kilometers above the earth's surface, and in this region, the temperature generally decreases with altitude, clouds form, and convection is active. On occasions, a tropical air mass may move in and instead of the temperature decreasing at a constant rate with altitude, it will be found to first decrease and then increase as the altitude of the tropical air mass is reached. Such a change is referred to as a temperature inversion.

As experimentation progressed to determine the characteristics of very-high-frequency waves, it was discovered that at times, particularly during the summer, strong fields would be observed at receiving points many miles beyond the horizon, and that the field intensity of the signals showed strong variations and produced effects similar to fading of high-frequency waves.

Ross Hull, an amateur experimenter, made some very interesting studies of long-distance transmission and reception of very-high-frequency waves and showed that there is a direct correlation between signal intensity and temperature inversion. That is, when warm air masses exist above colder air masses near the ground, the signals are bent or refracted down to earth beyond the horizon by the warm air and its water vapor. The bending is proportional to the gradient of the dielectric constant of the atmosphere, which in turn is proportional to the sum of the gradients of the dry air and water vapor constituting the atmosphere.

Refraction of very high frequencies at air mass boundaries, i.e., tropospheric discontinuities, has resulted in some very unusual radio transmissions in the field of the amateur, F–M and VHF police service, as well as radar.

During the war, on occasions, reflection from clouds produced false targets on low-frequency radars, causing much concern to responsible officers. In connection with weather observations, the heights of clouds have been measured with radar reflections.

16–12h. Shadows—When considering the propagation characteristics of very high frequencies, we must include a discussion of the results to be expected when the transmitting and receiving stations are on the opposite sides of a hill, or other similar interference exists in the optical path. In such a case, whether or not reception is possible at the receiving point depends upon several factors, such as the distance of the transmitting antenna to the obstruction, the distance of the receiving antenna to the obstruction, the height of the obstruction, the frequency employed, and the polarization of the transmitted wave.

Points behind hills and ridges where the signal is below normal are referred to as "shadow areas" (see Figure 16–18). It is possible to find "dead spots" within the shadow area; however, moving an antenna a wave length or two, or even a shorter distance from the dead spot, may result in producing a strong signal. In other words, at these frequencies standing waves, made evident by points of maximum and minimum and even zero signal intensity, are prevalent. Information supplied the Federal Communications Commission in connection with its hearing on allocation of frequencies from 10 kc to 30,000,000 kc included a report made by the firm of Jansky and Bailey on the effect of hills and trees as obstructions to radio propagation. Tests were conducted with low transmitter antennas, from 19 to 29 feet above ground, located both on hills and in low terrain, and with propagation paths over 1000- and 660-foot ridges and over an 8000-foot mountain. The report describes propagation over obstructions as follows:

> "The magnitude of a wave propagated over a ridge or mountain is modified by two factors. First, a loss occurs due to the diffraction of the wave as it bends over the crest, and second, a gain is accomplished due to constructive interference resulting from the increased number of ray paths arriving at the receiving point. At locations close to each side of the ridge, the loss due to diffraction predominates and the field intensity is appreciably less than would be experienced with the transmitter and receiver spaced an equal distance apart with no obstruction between. However, when one or both terminals are removed a sufficient distance from the obstructing ridge, the diffraction loss and the multiple path gain are balanced and the field intensity is a normal value. At all greater distances, the field intensity will be even greater than the normal unobstructed value.
>
> "Mr. Bailey summarized the shadow data, using for an example the tests made with a 1000 foot obstructing hill between transmitter and receiver, as follows: Directly behind the hill the shadow is quite a lot deeper on higher frequencies, but as the receiving point is extended further away, a healing effect takes place and the field intensity increases to a value greater than that which would be obtained without an intervening hill. . . ."[8]

14–12i. Bursts of Signals—While making observations and recordings of certain F–M and television stations operating in the frequency range from 42 to 84 mc at Laurel, Maryland, in 1942, the Field Division of the F.C.C. detected a signal in the form of bursts lasting for a period of a few tenths of a second duration and in some instances sustained for several seconds or longer. Recorders at Grand Island, Nebraska, registered signal bursts from a station 1400 miles away.

The number of bursts, the intensity of the bursts, and the intensity of the highest bursts decreases

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[8] Federal Communications Commission Docket No. 6651 of May 25, 1945.

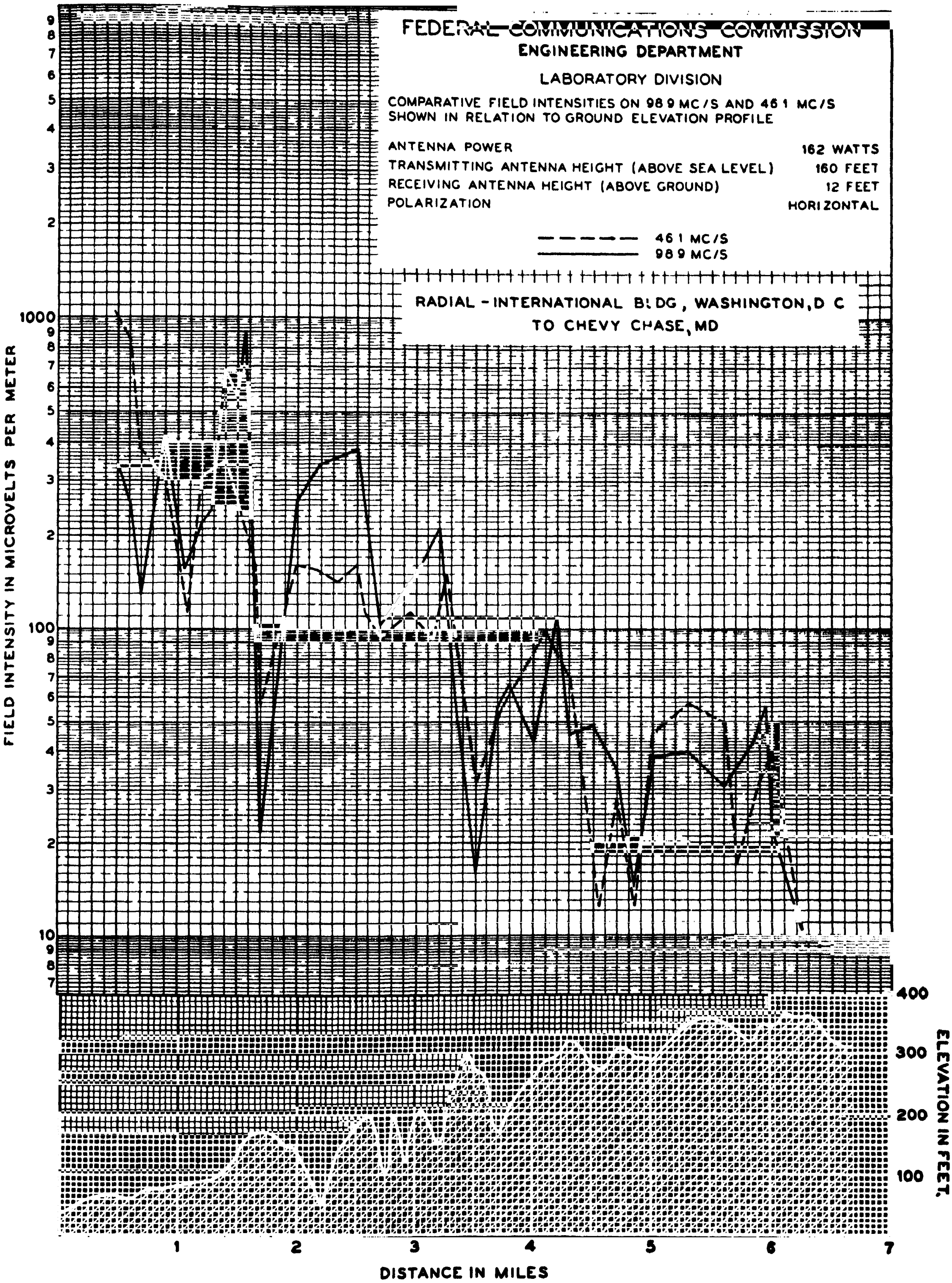

Fig 16–18 Graph showing field intensity versus distance over a path containing many shadow areas. Field intensity values for two different frequencies are shown

with distance, and furthermore, occur less frequently and are of shorter duration at 71 mc than at 44 mc. Their maximum amplitudes are about the same at both frequencies for a given radiated power. The interference effects to radio services occupying these frequencies have yet to be determined. As reported in F.C.C. Docket No. 6651:

> "When the bursts were first identified as being something other than peaks of rapidly fading tropospheric waves, several possible causes were advanced by those who had observed them, such as reflection from aircraft, from undulating tropospheric discontinuities, or from patches of ionization. A further extension of the latter theory was to the effect that the patches of ionization were caused by the passage of meteorites through the upper atmosphere. The ionization effects of meteors in connection with radio propagation at lower frequencies had been investigated by A. M. Skellett and J. A. Pierce, and the occurrence at 10 mc of bursts of somewhat longer duration than those at 40 to 50 mc had been attributed to meteoric ionization by Pierce. Short-distance scatter effects at 10 mc which consisted of bursts of from one half to one second duration had also been investigated by T. T. Eckersley and attributed to patchy E layer ionization.
>
> "During June 1944, after the agreement between the occurrence of meteors and bursts had been established, a few observations were made at Laurel in an attempt to obtain coincidences between bursts and visible meteors. Several meteors were seen, but none having a proper direction of flight, so that the ionized track was capable of reflecting the signal to the receiving point. Beginning on August 1, a continuous watch was kept between 9 and 10:05 pm, E.S.T. on favorable nights by two or more observers at the home of one of the engineers. Two coincidences were observed on August 6, in which the meteor track was approximately transverse to the signal path. On August 8 and 11, two coincidences were observed each night in which the meteor track was along the plane of the signal path. The last meteor was of particular brilliance with a persistent visible train, and the signal was sustained for about ten seconds. The meteor was somewhat beyond the receiving point with sufficient inclination of the track to reflect the signal back at an acute angle. Had a meteor of this size with the proper orientation been near the center of the signal path, the duration would have been several times as great. Sustained bursts of this type appear frequently on the records near the times of the regular showers of visible meteors.
>
> "Bursts have also been recorded at Laurel on 71.75 mc from television station WRGB. They are less frequent than at 44.3 mc, of somewhat less duration on the average, and their maximum amplitudes are about the same for a given radiated power."

Additional coincidences between bursts and visible meteors were observed by F.C.C. engineers during 1945.

16–12j. Sporadic E Reflections—In addition to the signals which travel via the lower atmosphere referred to previously as the troposphere, a third type of signal which is reflected from patches of abnormally high ionization in the *E* layer make the reception of very-high-frequency signals possible over long distances, in fact, hundreds of miles beyond the optical path or first horizon. Transmission via reflection from sporadic *E* patches is not distributed uniformly over the entire year but is largely concentrated within the summer months. Because of the unevenness in distribution of the patches, the points of reception are not uniformly distributed. It was not uncommon in the F–M service (42 to 50 mc band) for a station hundreds of miles away to take control over a local station when the receiving point was near the outer limits of primary service of the local station, or at some other point where the signal intensity was less than that of the reflected signal. Deep fading, often the case with sporadic *E*, may cause desired and undesired signals to alternate control in rapid succession. It appears from information now available, that the intensity of the signals reflected from sporadic *E* layers decreases logarithmically with an increase in frequency. For a small percentage of time, sporadic *E* reflections may be experienced at frequencies greater than 100 mc over distances as great as 1000 miles.

In the auroral zones, during ionosphere storms there occurs strong, widespread and continuous intense sporadic *E* transmission lasting for many hours and resulting in considerably improved radio reception in certain directions and over some paths while the storms last.

16–12k. F_2 Layer Reflections—It has been predicted that during periods of maximum sunspot cycles very high frequencies, at least up to 120 mc, will be propagated over distances ranging from approximately 1300 to 2500 miles.

Television signals on a frequency of 45 mc, of sufficient intensity to produce pictures, have been observed in New York from London as a result of F_2 layer reflection. Obviously, transmission over such long paths could not be relied upon for communication requiring constant service, but because of the interference possibilities, they do present a problem in allocation of frequencies to various services.

It has been previously stated that there are two ionosphere layers, which are termed the F_1 and F_2 layers. Reflections from the F_2 layer are of the greatest concern when considering propagation of radio waves above 30 mc.

The ability of the F_2 layer to reflect radio waves back to earth depends upon several factors, namely the period of the sunspot cycle, the number of sunspots, season of the year, hour of the day, the angle of reflection and the frequency of transmission. During the maximum of the last sunspot cycle in 1937–1938, the F_2 layer reflected signals above 40 mc at distances of several thousand miles during certain daylight hours of the winter months. The next sunspot maximum is expected about 1948–49. The sunspot cycles are of two opposite kinds, resulting in a full cycle of about 22 years.

The Federal Communications Commission's monitoring stations at Portland, Oregon, and San Leandro, California, have recorded graphically a number of F_2 layer transmissions in the band 42–50 mc from F–M stations located in the United States at distances ranging from 1850 to 2680 miles. During the period from October 22, 1946 to March 31, 1947, signals exceeding an interfering level of 25 microvolts per meter were received from 13 stations during 104¼ hours. At San Leandro, California, the signals reached a maximum of 4.7 millivolts per meter. Best reception occurred between the hours of 11:00 A.M. and 5:00 P.M., C.S.T., and at times a single station could be heard continuously for as long as 3 hours. Numerous reports have been received from police radio services regarding interference in the 30–40 mc band caused by F_2 layer transmissions from distant, low power radio stations, including stations in the United States as well as in European and South American countries. No F_2 layer transmissions have been reported on the 88–108 mc F–M band.

16–12l. Super Refraction and Trapping—Elsewhere in this volume the general characteristics of metal wave guides and their application in conducting microwaves from one place to another are described (p. 720). As the use of radar was pushed up into the microwave spectrum, it was discovered that at times radar signals traveled far beyond the optical path, apparently in fairly well defined paths or ducts in the earth's atmosphere, returning to the point of origin with less than the normal attenuation. Originally termed "anomalous propagation," this phenomenon is now generally termed "super refraction." From these observations a theory was postulated that under certain nonstandard conditions of the atmosphere, layers or ducts are formed which conduct radio-frequency waves in the same manner as a wave guide. This phenomenon develops when the temperature and humidity conditions are such that the downward bending of a radio ray is greater than the earth's curvature. A sharp decrease of humidity with altitude associated with a temperature inversion is the usual cause of an atmospheric duct.

These atmospheric ducts exhibit the same characteristics as wave guides, which can conduct efficiently only frequencies whose wave length is shorter than the critical or cutoff wave length. In other words, as the frequency is decreased there will be encountered a frequency below which it will not be possible to transmit via the atmospheric duct. Moreover, since these ducts act as true wave guides, the energy spreads only in two dimensions and the attenuation factor is so small that the energy does not decrease inversely with the square of the distance.

There is also an upper frequency limit, above which the duct is ineffective. It is caused by the rough surface of the earth which tends to scatter the energy from the surface, thus causing it to be lost.

Atmospheric ducts are sometimes referred to as ground-based ducts, since the atmosphere forms one of the boundary surfaces and the earth's surface the other boundary. The effects of atmospheric ducts are more pronounced in the microwave bands, 3000 mc and up, but they do exist at frequencies as low as 20 mc.

The atmospheric ducts which are most significant from a radio propagation standpoint are generally considered to be below an upper limit of 3000 feet. The type of ducts which occur on land surfaces are of the order of 100 to 500 feet. Consequently, it can be seen that the height of the antenna is an important consideration when it is desired to overcome the effects of trapping resulting from the formation of ducts.

The angle of approach of the radio wave determines whether or not it will be trapped in a duct. Observations to date indicate that unless the wave approaches the duct at an angle of one-half a degree or less it will not be trapped.

A signal from an ultra-high-frequency antenna might enter an atmospheric duct and be so trapped as to carry it far beyond the normal optical path and be bent back to earth in the service range of a similar station, with the possibility of interference. It is also possible for an aircraft flying above a duct of this kind to have its signals trapped, preventing communication with a ground station below the duct, even though an optical path may prevail. Under such conditions, the aircraft's signals might be heard at an airport hundreds of miles beyond the optical path. The effect is not unlike the skip distance phenomena experienced on frequencies much lower in the spectrum and, in fact, can be calculated, if certain meteorological conditions are known.

16–12m. Effects of Rainfall on Microwave Propagation—Tests conducted by engineers of the Bell Telephone Laboratories disclose that rainfall of the magnitude of a cloudburst may attenuate 3.2 centimeter waves by as much as 5 db per mile, whereas the attenuation at this frequency is slight for moderate and light rainfall.

At 1.09 centimeters, the waves are appreciably attenuated even by a moderate rain. Attenuation in excess of 25 db per mile have been observed during a cloudburst at this frequency. The losses are still higher at 0.62 centimeters, reaching a value of 42 db per mile during a cloudburst.

16–12n. Complementary Diversity Reception of Microwaves—The Office of the Chief Signal Officer in Propagation Report No. 2, by Thomas J. Carroll, in connection with comparative tests of radio relay equipment, explained the utility of what the engineers of the Radio Propagation Section of the Plans and Operations Division, termed "complementary diversity" reception of microwaves, a form of diversity reception in which a second receiving paraboloid or "dish" antenna, is vertically spaced so that deep signal fades on one antenna are coincident with strong signals on the other. This method of microwave reception, it is stated, appears to have wide application to nearly all micro-

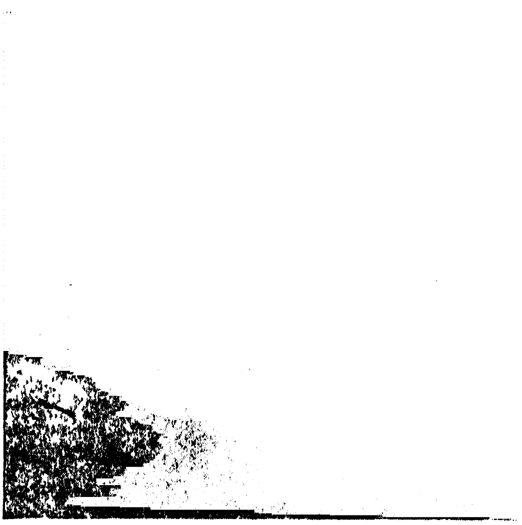

FIG. 16–19. Antennas employed in a test of complementary diversity microwave reception. The second receiving antenna is attached to a pole fifty feet lower than the others. (Courtesy Bell Telephone Laboratories.)

wave radio circuits over optical paths as a scheme for overcoming fading caused by vagaries of propagation.

Fading of microwaves over most optical paths results from interference of both direct and reflected signals. Tests conducted on frequencies between 4300 and 4900 mc disclosed that the lobe pattern fluctuates up and down almost continuously as a result of atmospheric changes over the path of propagation. Reflection of the microwaves from the ground was found to be the cause of fading on a 170 mile optical path over land on which the direct ray path cleared the land by 1000 feet in the standard atmosphere. Using two antennas for reception (Figure 16–19) was more effective in overcoming deep fades than a ten-fold increase in power (10 db).

In the discussion of vertical spacing of the lobes of radiation, Dr. Carroll reported as follows:

"In transmission between two points above the horizon about as much signal reaches the receiver by reflection from the sea or land surface as passes directly above the ground. When the path difference between the direct and reflected rays is a whole number of wave lengths, the two signals arrive at the receiver out of phase and give a very low resultant field strength, for the usual case where the reflected wave suffers a 180 degree phase reversal on reflection.

"When the path difference is an odd number of half wave lengths, the two signals arrive in phase and give a resultant field strength twice that of free space. The lobes are more numerous the higher the antenna and the shorter the wave length. Neglecting earth curvature, the angular spacing between lobes in radians is just wave length/2 × antenna height.

"In the actual atmosphere, however, the lobe positions cannot be presumed to be absolutely steady, for changing temperature and moisture gradients in the atmosphere change the ray paths enough to alter the path difference between the direct and reflected signals. Only a half wave length change in path difference in the atmosphere causes the signal to fluctuate from maximum to minimum at a fixed receiver height; half a wave length is only 3 cm for TRC 6 frequencies. The lobes may be thought of as oscillating up and down somewhat as a result of small deviations of the temperature and moisture gradients from those in a standard atmosphere. The half lobe spacing in the standard atmosphere is chosen for complementary diversity on the assumption that the spacing between the lobes will change only slightly as they move up and down with atmospheric changes. Thus, as a deep fade occurs at one paraboloid, the other can be expected to be receiving approximately a maximum signal. Aircraft flights at the Navy Radio and Sound Laboratory, San Diego, have shown that the signals at the minima are 25 db or more less than those at the maxima of the lobes.

For terminals near the horizon, earth curvature becomes important in the actual spacing of the lobes, so that the actual spacing is larger than would be calculated for a flat earth. The calculation is tedious, but it is expected that a simple chart can be produced ultimately, which will give the lobe spacing in feet directly when the distance and antenna heights above the reflecting surface are known."

As the result of these tests, it was concluded that complementary diversity reception is necessary over all microwave paths operating over smooth reflecting surfaces, such as the sea, or reasonably smooth reflecting land, and is beneficial at times over all but the most rugged terrain. Furthermore, an increase of transmitting power is inefficient as compared to diversity reception to overcome the effects of fading over optical microwave paths.

CHAPTER 17

ANTENNAS

It has long been the custom of radio textbooks and handbooks to approach the subject of antennas from the transmitting standpoint. We shall follow this custom, although a warning against certain misunderstandings that this approach may create is necessary.

1. While it is easier to describe and to visualize the operation of the transmitting antenna, its actual importance is *not* greater than that of the receiving antenna.

2. It is true that the insulation of a receiving antenna may be modest, since very little power is present. However, it is quite incorrect to believe that any length of wire is good enough for receiving. The use of such antennas is a concession to cost or convenience. The "plain wire" is not a good collector, neither does it contribute any directional effect. For both reasons it tends to give noisy reception. Its main merit is the ability to work over a wide range of frequencies, although at low efficiency.

3. A good transmitting antenna is also a good receiving antenna: in many commercial radio circuits the same specialized directional antenna serves both purposes. "Antenna gain" is quite as useful at the receiver as it is at the transmitter.

The reader is asked to keep these comments in mind and for each transmitting antenna effect he may visualize the corresponding effect during reception. In the latter part of the chapter receiving is given more attention.

17-1. Voltage and Current Distribution—An antenna possesses inductance, capacitance and resistance, which are distributed along the wire. In the case of the simple ungrounded half-wave antenna (the Hertz antenna shown in Figure 17-1) the inductance is distributed fairly evenly along the wire. There is an end-to-end capacitance and in addition each portion of the wire has capacitance with respect to all other portions. When this antenna is fed by a radio transmitter, the distribution of current and voltage is not uniform along the wire but varies somewhat as shown by the curves. The points of greatest current or voltage are known as "loops" and the points of zero voltage or current are known as "nodes." The current and voltage distributions shown indicate the name *half-wave antenna*. Its uses will be amplified later.

If one end of a vertical wire is grounded we have the simplest form of the grounded (or Marconi) antenna, as shown in Figure 17-2a. When it is fed by a transmitter, the voltage and current distributions tend to be somewhat as shown. This is reasonable since grounding has made it impossible to produce a high voltage (voltage loop) at the lower end. Instead there is a current loop at this point, and it is a *quarter-wave antenna*. This type also has practical importance.

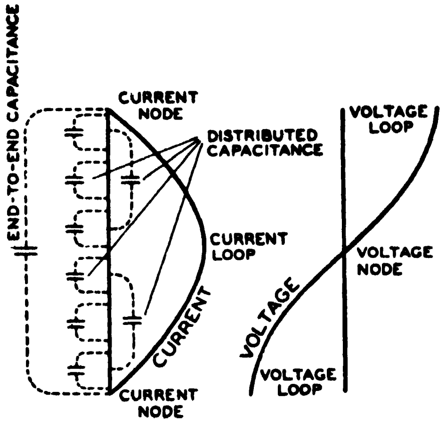

Fig. 17-1. Half-wave ungrounded antenna.

If the radio transmitter connected to the grounded antenna is operated at (about) three times the frequency (one-third the wave length), it is possible to cause the antenna to operate in the manner of Figure 17-2b, that is, as a *three-quarter-wave antenna*, and this is occasionally done, though such operation is less common than operation as in Figure 17-2a or at a condition intermediate between Figure 17-2a and 2b. (These intermediate methods require additional equipment as explained in Section 17-3).

Actual antennas do not consist of a straight wire which touches nothing. The distribution of current and voltage is therefore further modified by the presence of supports, all of which add capacitance and resistance. To some extent they also change the inductance. The practical antenna departs from the ideal Hertz and Marconi types, particularly where the lower end is near the earth or connected to it. In such a case, as in Figure 17-2a or 2b, there is very considerable capacitance between antenna and earth, the capacitance being highest near the ground and decreasing up the antenna. As the current travels up the antenna, each of these distributed capacitances is charged and the value of the current falls off.

It is possible to raise the center of capacitance of an antenna by top-loading it with capacitance, which may take the form of a horizontal wheel or outrigger arms. This top-loading tends to increase the current in the higher portions of the antenna.

17-2. Resonant Frequency—In Figure 17-1 it was assumed that the electrical wave length was twice the actual length of the ungrounded antenna. Similarly in Figure 17-2a the electrical wave length was assumed to be four times the actual length of the grounded antenna. Actually the unwanted capacitances of the practical antenna, which were mentioned in the foregoing paragraph, always load the antenna so that it must be shortened a little to work at the desired wave length. However, when the practical equivalent to the ideal antenna of Figure 17-2a has been so shortened as to become resonant at the required frequency, it is still called a quarter-wave antenna and behaves much like the ideal quarter-wave antenna. At its resonant frequency it acts as a pure resistance just as any tuned circuit does, if used at resonance. A radio transmitter which is to feed the antenna accordingly must be designed to work into a resistive load. If the antenna is fed near the earth, as is usually the case, it is necessary to supply a large current at a low voltage, which is to say the antenna "looks like a low resistance." It is operating at its fundamental frequency.

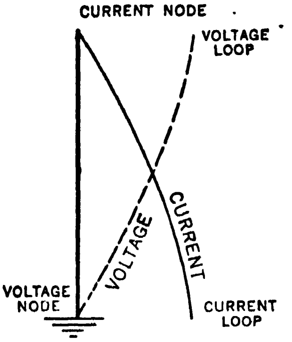

FIG. 17-2a. Distribution of current and voltage of a grounded quarter-wave antenna.

If the exciting frequency applied to a vertical grounded antenna is increased only a little, the antenna is no longer a pure resistance; it acquires inductive reactance. This inductive reactance increases as the exciting frequency is increased and reaches a high value just before the exciting frequency becomes twice the fundamental frequency. Just beyond this frequency the antenna reactance again has a high value but is substantially capacitive. As the exciting frequency is increased further, this capacitive reactance decreases until the antenna once more acts like a resistance when the exciting frequency is approximately three times the fundamental frequency and the voltages and currents are distributed as in Figure 17-2b.

When the exciting frequency is such that the electrical length of the antenna is intermediate between a quarter-wave and a half-wave antenna, the reactance is inductive. Putting it differently, if the antenna of Figure 17-2a were too high to work as shown, it would not act as a resistance but as an inductance with resistance. It would not be resonant. It could be tuned to resonance by cutting it near the earth and inserting a series condenser. Such a condenser has been called a "shortening" condenser. If the antenna is less than a quarter wave it may be (electrically) lengthened by inserting an inductance (lengthening or base-loading coil).

In the case of the half-wave antenna of Figure 17-1 we also have resonance; the antenna acts as a resistance but the ends are at high voltage. The same is true of a full-wave antenna. Such antennas cannot be connected to earth through a low impedance as can the quarter-wave and three-quarter-wave antennas. They must (if fed from the end at all) be supplied with a small current at high voltage; in other words, the end of the antenna "looks like a high resistance."

It is seldom possible to build an antenna whose resistance and resonant frequencies are precisely those desired. Therefore the feed equipment at the base of the antenna is usually adjustable. In order to adjust it intelligently it is necessary to measure the antenna as described in later sections of this chapter. The methods are standardized to simplify discussion between station owner and governmental agencies.

17-3. Practical Importance of Vertical Antenna Height—The grounded vertical quarter-wave antenna of Figure 17-2a would seem to be the simplest and most desirable of the entire family of grounded antennas. This is not invariably true. There are times, especially at long waves (low frequencies), when a quarter-wave vertical structure is too costly or (at very long waves) altogether impracticable. It is then necessary to use a lower antenna with capacitive top loading and, perhaps, inductive base loading. The efficiency is usually somewhat discouraging.

On the other hand, heights intermediate between one-quarter wave and one-half wave are extensively used, mostly in the frequency range 500 to 1700 kc, in spite of their cost. The reason lies in the fact that a grounded vertical antenna radiates equally in all compass directions regardless of its height, but tends to waste much of this radiation by sending it at high angles. This high-angle radiation is useless in the near-by "primary service area" of a station which is intended to blanket an area with signals, as in commercial broadcasting. In fact the high-angle radiation is somewhat worse than useless since it is eventually reflected downward from the "Heaviside layer" of the upper atmosphere in an erratic manner, serving only to pro-

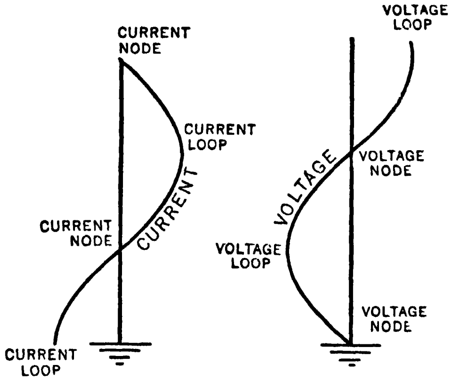

FIG. 17-2b. Distribution of current and voltage of a grounded three-quarter-wave antenna.

duce garbled signals in certain regions. The high-angle radiation can be reduced and the desired low-angle radiation increased by making the antenna more than one-quarter wave high. Figure 17-3 shows the theoretical result, with the usual assumption of a vertical antenna not requiring supports. Referring to the left half of the illustration, which compares results for the same antenna power, it is seen that the higher antennas transmit more low-angle radiation but also that there is a limit to satisfactory transmission. If the antenna is made 0.625 wave length (⅝ wave) high, it develops a new high-angle output, a so-called "secondary lobe of radiation."

It will be noticed in the right half of the figure that antenna heights are sometimes stated in electrical degrees. One wave length is 360 electrical degrees, one-quarter wave length 90 degrees, and so on.

17-4. Antenna Resistance Measurements—If the antenna resistance is known, it is possible to determine the efficiency of the transmitter as well as the antenna. The effective antenna resistance, which is measured in ohms, comprises three distinct resistances likewise measured in ohms. They are radiation resistance, ohmic resistance, and dielectric absorption resistance.

Radiation resistance is the only useful resistance since power expended in this resistance is instrumental in producing the signal at a distant station. It is this quantity multiplied by the square of the antenna current that determines the radiated power, that is, the power of the radiated waves. The radiation resistance of an antenna depends upon the effective height of the antenna, its shape, and the frequency at which it operates. Radiation resistance is at a maximum at the fundamental frequency and decreases rapidly as the antenna is loaded. The power delivered to an antenna is equal to the square of the antenna current multiplied by the effective resistance. The resistance must be measured at the same part of the antenna as the current. Thus it can be seen that the efficiency of the antenna as a radiator is the ratio of the power radiated to the power which is being fed to the antenna. If half the antenna input is radiated, the radiation efficiency is 50 percent.

Ohmic resistance is not useful. It is the resistance which causes heat losses caused by the current flowing in the antenna wires, ground wires, and any other conductors comprising the antenna circuit including the earth itself. The value of this resistance remains virtually constant over a wide range of frequencies.

Dielectric absorption also has the effect of resistance since it represents another power loss. It is due to imperfect dielectrics within the field of the antenna, such as masts, guys, trees, buildings, and on shipboard, the funnel of the vessel. The value of this resistance increases in proportion as the antenna is loaded. Ohmic and dielectric losses are combined and called *the effective loss resistance.*

For the practical purpose of measuring the power input to the antenna the three resistances are combined and called *the total antenna resistance.*

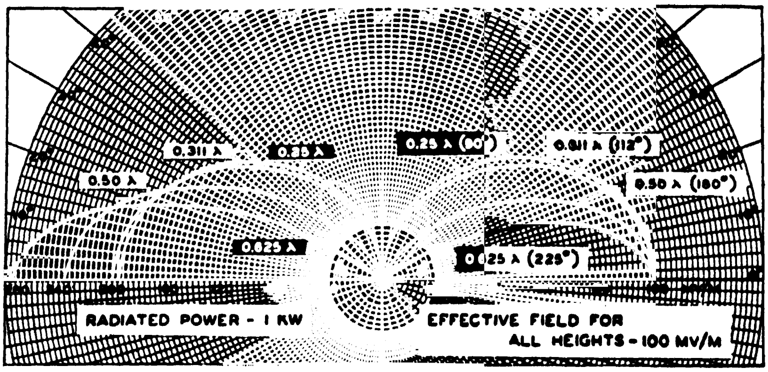

FIG. 17-3. Vertical radiation patterns for different heights of vertical wire antennas (sinusoidal current distribution).

The radiation efficiency can be expressed by the formula:

$$\text{Efficiency in percent} = \frac{R_r}{R_r + R_l} \times 100$$

where R_r is the radiation resistance and R_l the loss resistance, consisting of ohmic and dielectric losses taken together. Hence it can be seen that if the radiation resistance is high compared to the loss resistance, the antenna efficiency will be high.

17-5. Ground Systems—When an antenna is worked against ground, the ground connection always introduces a loss resistance. In unfavorable soil this resistance may be large (30 to 100 ohms). An effort is always made to keep the resistance losses low. This is accomplished, generally, by burying wires directly beneath the surface of the earth and extending them as radials of equal length in all directions from the antenna, like spokes extending from the hub of a wheel. In the "standard broadcast" service 120 buried radial copper wires, each 0.4 wave length long, are commonly employed. Under favorable soil conditions these wires provide an excellent ground connection. Sometimes wire screens and metallic plates are buried beneath the earth to make a low-resistance ground circuit. In certain low-frequency high-power transmitting stations with very large antenna currents, a special type of antenna is employed to reduce the earth resistance further by using several ground-connections, each carrying a part of the total current. Such an antenna has a long horizontal "flat top" with several downleads. It is called a "multiple-tuned" antenna and in effect constitutes a number of separate radiating antennas in parallel, each having its own tuning inductance connected independently to earth at equidistant points.

17-6. The Counterpoise—In cases where a buried ground system cannot be provided, a "counterpoise" is often substituted. A counterpoise consists of one or more wires usually stretched directly beneath the antenna but elevated above, and insulated from, the earth. The antenna circuit is then completed to earth through the capacitance between the counterpoise and the earth. This arrangement is not as efficient as a large buried ground system and is used only when the installation of an adequate buried ground is not feasible. In temporary installations the counterpoise may be useful. Like the buried radial ground system it is best when made of many radial wires. In extreme cases a high-resistance ground connection of small area may be aided by combining with it a moderate counterpoise, using two ground leads, separately tuned.

17-7. Measurements of Antenna Resistance—There are three basic methods of measuring the resistance of an antenna. They are termed the variation, substitution, and bridge methods. These three methods are acceptable for measuring the total antenna resistance of a standard broadcast antenna in accordance with the F.C.C. requirements. They are applicable to other *grounded* antennas. The apparatus required includes:

(a) Radio-frequency generator to cover the frequency range necessary, power 50 watts or required power when using bridge method.

(b) Wavemeter for broadcasting frequency; accuracy 0.25 percent.

(c) Decade resistor having steps of units, tens and hundreds ohms resistance, or equivalent; accuracy, 1.0 percent.

(d) Radio-frequency galvanometer or milliammeter of approved type; accuracy 2.0 percent.

(e) Approved tuning condenser of approximately 0.001-μf capacitance and tuning inductance approximately 60 mh.

(f) Suitable bridge if this method is used.

17-7a. Measurement of the Resistance of Directional Antenna Arrays—The broadcast transmitter is not usually satisfactory for use as the source of radio frequencies. Another oscillator of adjustable frequency should be used. The maximum power dissipated in the antenna while making measurements should not be over 10 percent of the power available from this radio-frequency generator.

An accurate determination of the antenna resistance can only be made by taking a series of measurements, each at a different frequency. From 10 to 12 resistance measurements covering a band 40 to 60 kc wide and centered on the assigned operating frequency must be made to give data from which accurate results may be obtained.[1] The values measured should be plotted with frequency as abscissa and resistance in ohms as ordinate and a smooth curve drawn. The point on the ordinate where this curve intersects the operating frequency gives the value of the antenna resistance.

Licensees of broadcast stations authorized to employ directional antenna systems desiring to determine the operating power by direct measurement of the antenna power can determine the resistance by the following method:

Measure the resistance at the point of common radio-frequency input to the directional antenna system. The following conditions and procedure obtain:

(a) The antenna shall be finally adjusted for the required field pattern.

(b) The reactance of the antenna at the operating frequency and at the point of measurement shall be adjusted to zero or as near thereto as practical.

(c) A suitable radio-frequency bridge or other device shall be employed to determine the resistance and reactance at the point of common radio-frequency input in the same manner as set forth above for a single antenna.

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[1] Assuming the assigned frequency to be in the 500–1600 kc range.

(d) Resistance and reactance measurements at approximately 5, 10, 15, and 20 kc on each side of the operating frequency shall be made. The values measured shall be plotted and the resistance at the operating frequency determined in the same manner as for a single-element antenna.

(e) A permanently installed antenna ammeter shall be placed in each element of the system as well as at the point of measurement of resistance, with the remote reading ammeters located in the transmitter room. The application for authority to determine power by the direct method shall specify not only the current at the point of resistance measurement for the authorized input power (I^2R in accordance with section 3.54 of the Rules Governing Broadcast Stations, see Chapter 20 and (f) below) but also the current of each element of the system when adjusted for the required pattern and for the authorized operating power.

(f) The license for a station of power of 5 kw, or under, which employs a directional antenna and determines the power by the direct method, will specify the antenna resistance as 92.5 percent of that determined at the point of common input in accordance with the above. The resistance specified for stations of a power over 5 kw will be 95 percent of that determined at the point of common input.

17-7b. The Variation Method—The variation method of antenna resistance measurement is accomplished by inserting a standard or known value of non-inductive resistance in series with the antenna and ground and noting the change in the reading of the antenna current ammeter. The circuit arrangement for such a measurement is shown in Figure 17-4. It will be noted that the antenna coupling and loading inductance (if used) are in the circuit also a variable condenser to permit measurements above as well as below the fundamental frequency of the antenna. The shielded terminal of the condenser should be connected to the ground.

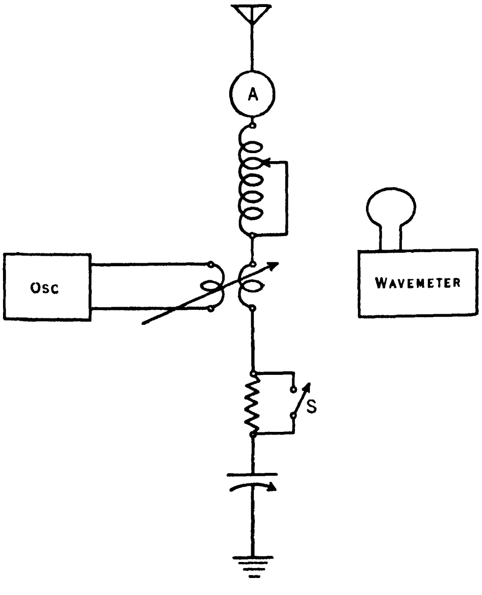

Fig. 17-4. Arrangement for antenna resistance measurement by the variation method.

In order to measure the resistance at the fundamental frequency of the antenna the natural period of the antenna system must be found. This is done by connecting the antenna directly to the ground or counterpoise. If a grid current milliammeter is included in the driver circuit a pronounced dip of the needle will be indicated when the driver is in resonance with the natural frequency of the antenna system. If an antenna milliammeter is included in the antenna circuit it should indicate its maximum deflection when the grid meter makes its lowest dip. The deflection of the grid meter should be gradual as resonance is approached on either side. A very sharp dip of the needle with a sudden return to its normal position indicates too close coupling between driver and antenna circuit. The coupling should be further loosened until there is absolutely no reaction between the two circuits. A powerful driver separated by several feet from the antenna is necessary if accuracy is desired.

After determining the fundamental frequency of the antenna its resistance at this frequency can be measured.

The antenna circuit at resonance is noted and then the known resistance is put in series with the circuit and the antenna current read again. The power output of the oscillator should not be disturbed when the known resistance is inserted in the circuit. The antenna resistance in ohms is obtained from the formula,

$$R_a = \left(\frac{I_k}{I_a - I_k} \right) R_k$$

where I_a is the antenna current with R_k the known resistance short-circuited or out of the circuit, and I_k is the antenna current with R_k in the circuit.

Having determined the resistance of the antenna at its fundamental or natural period the loading and coupling inductors and tuning condenser should be tied-in and a measurement made at the operating frequency. Measurements should be made at 5-kc intervals, 30 kc above and below the operating frequency.

Extreme care should be exercised to prevent energizing the antenna at points other than at the coupling coil such as might happen if the oscillator is improperly shielded or if stray capacitances exist between the coupling link and the antenna circuit.

Laport has described a variation resistance measurement procedure [2] which permits a high degree of accuracy and permits the operator to determine if stray capacitance exists between the measuring circuit and ground. The circuit arrangement is shown in Figure 17-5.

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[2] Laport "Influence of Stray Capacitance." *Proc. I.R.E.*, May, 1934.

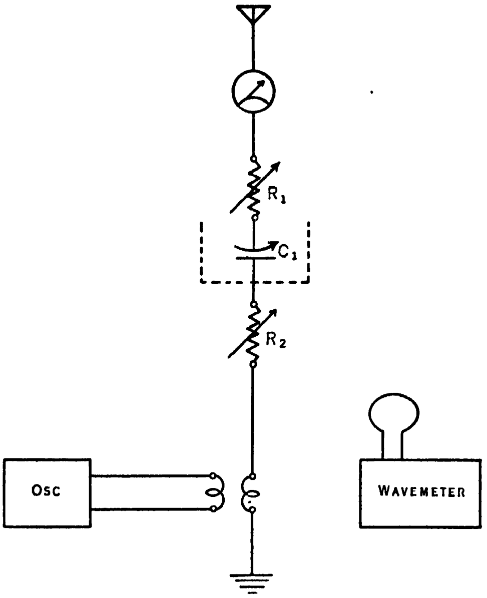

FIG. 17-5. Two-resistor method of antenna resistance measurement.

17-7c. Alternate Variation Method—Two standard resistors are required. The tuning condenser should be a precision calibrated condenser for reactance measurements according to Federal Communications Commission's requirements. The shielded terminal of the condenser should be connected to R_2. Measurements are made as follows: R_1 and R_2 are set at zero resistance. The circuit is tuned to resonance by the condenser C_1 as evidenced by maximum antenna current. Some adjustment of the exciting voltage may be necessary to obtain a convenient deflection of the ammeter. When exact resonance is found, known values of resistance R_1 are cut in and the antenna current noted and the resistance computed from the formula shown in the description of the first method. Then R_1 is set at zero resistance and similar measurements made using R_2. If there is no appreciable stray capacitance between the measuring circuit and ground the resistance values given by R_2 will agree with those obtained using R_1, but if there is an appreciable amount of stray capacitance, the two sets of measurements will not agree. The arrangement of the instruments should then be changed and measurements made until the two are in substantial agreement.

The truest results will always be obtained by using resistance R_1 and the final measurements made with this resistance.

The reactance of the circuit at the point where the resistance was measured can be determined from the calibration of the condenser at the resonance setting or

$$X_c = \frac{1}{2\pi fc}$$

where f = resonance frequency and c the capacitance of the condenser at resonance.

When an inductance is also used in the measuring circuit, the net resultant reactance of the tuning elements will be equal to the antenna reactance.

Considerable care is necessary when making measurements of high impedance antennas, especially those close to a half wave.

17-7d. Substitution Method—Measurements of an antenna resistance by the substitution method as the name implies consists of the substituting for the antenna an artificial antenna, comprising inductance or capacitance and resistance. The inductance employed to couple to the transmission line or final amplifier and any inductance necessary for loading should be used in the antenna circuit, thereby permitting a more accurate determination of the total antenna resistance. It is assumed that the antenna is resonant at the working frequency. Since at resonance the reactance has been made equal to zero by use of the antenna tuning means, only resistance remains and therefore the dummy circuit may also consist of a pure resistance.

A radio-frequency generator variable in frequency and with at least 50 watts output is required to drive or energize the dummy circuit. The circuit arrangement of apparatus is shown in Figure 17-6.

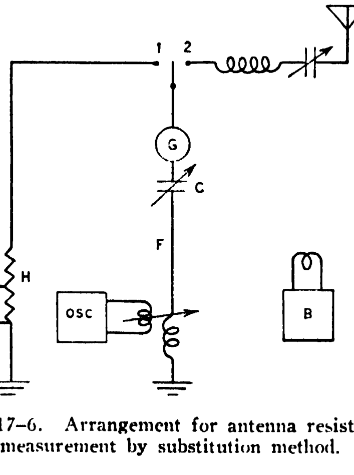

FIG. 17-6. Arrangement for antenna resistance measurement by substitution method.

It is imperative when making measurements that the apparatus be arranged so that no energy is coupled into the antenna circuit by stray capacities, otherwise, erroneous results will be obtained. In particular the oscillator must be well shielded so that stray coupling between the antenna and oscillator tank circuit is small as compared with the direct coupling employed to energize the antenna. The antenna energizing current should be as high as practicable for a given oscillator. This precaution is particularly important if the oscillator does not possess adequate shielding.

It will be noted in the requirements stipulated by the Federal Communications Commission that a wavemeter is required having an accuracy of 0.25 percent. The wavemeter, either of the absorption or heterodyne frequency type is required to adjust the driving oscillator to the operating frequency and the other frequencies both above and below the operating frequency, at which additional measurements are required.

The resistance at the operating frequency is determined by adjusting the oscillator or driver to the operating frequency and coupling the output to the antenna circuit and recording the antenna current as I_a. The antenna and ground are disconnected and the antenna inductances connected to the calibrated variable condenser C and resistance H. The output of the oscillator is kept constant and the condenser adjusted until the dummy circuit is resonant at the operating frequency as determined by the wavemeter. The resistance H is then varied until the ammeter current is the same value as that when the antenna and ground were connected. The value of the resistance is then equal to the antenna resistance and the reactance of the antenna is equal to the dummy condenser reactance.

17-7e. Other Use of Dummy Antenna—The dummy antenna circuit is also useful for testing purposes without the necessity of radiating a carrier wave. To find the antenna current when 500 watts of power are delivered to an antenna having a resistance of 10 ohms, substitute in the formula

$$I_a = \sqrt{\frac{P}{R_a}}$$

or

$$I_a = \sqrt{\frac{500}{10}} \quad \text{or} \quad I_a = 7.07 \text{ amperes}$$

where P = Desired antenna power
R_a = Antenna resistance
I_a = Antenna current

Another example of the use of these values is as follows: Suppose it is desired to adjust the same transmitter to 750 watts output at the same wavelength. The transmitter should be adjusted until the dummy antenna current is 8.66 amperes.

$$I_a = \sqrt{\frac{P}{R_a}} \quad \text{or} \quad \sqrt{\frac{750}{10}} \quad \text{or} \quad I_a = 8.66 \text{ amperes}$$

Proof: Watts in antenna = $I^2 \times R$
Watts in antenna = $8.66^2 \times 10$
Watts in antenna = 749.9

If 750 watts were put into the antenna and 450 watts were shown as energy lost by radiation the remaining 300 watts would be dissipated in heating the wires, ground connection, dielectric absorption, and by eddy currents induced in nearby wires and metal masts.

The artificial or dummy antenna built-in modern broadcast transmitters is also useful for making modulation tests and frequency runs.

17-8. Service Areas of Standard Broadcast Stations—The "Standards of Good Engineering Practice" of the Federal Communications Commission recognize three kinds of service areas for the several classes of standard broadcast stations operating in the band 550–1600 kc. These are, namely, primary, secondary and intermittent.

Primary service area (area of high dependability) results from the ground-wave signal having a sufficient level above noise and also above interfering sky-wave signals due to high-angle radiation either from other stations or from the station's own antenna system. Hence, every effort is made to choose a radiating system that will propagate the most energy along the ground and the least at high angles. In so doing, radiation which might be reflected from the ionosphere is suppressed, and hence fading within the primary service area is reduced. In addition the field intensity along the ground for a given radiated power is greater than it would be in the case where radiation is distributed over many angles above the horizontal.

Vertical antennas permit obtaining the best possible ground wave coverage in the broadcast service and, by proper choice of the antenna, fading at short distances is minimized. (See Section 17-3 of this chapter.) Vertical antennas can also be used in combination to establish directional service areas and thereby provide protection to other stations.

Sky-wave signals provide a secondary service area and, in the United States, protection to such service areas is provided for clear channel stations.

The "Standards of Good Engineering Practice" recognize that secondary service is delivered in the areas where the sky wave for 50 percent or more of the time has a field intensity of 500 microvolts or greater. The secondary service is necessarily subject to some interference and extensive fading, whereas the primary service area of a station is subject to no objectional interference or fading.

The intermittent service rendered by the ground wave of a standard broadcast station begins at the outer boundary of the primary service area and extends to the value of signal where it may be considered as having no further service value. The noise level, fading, and interference from other stations are determining factors with respect to the area of the intermittent service.[3]

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[3] The "Standards of Good Engineering Practice" concerning Standard Broadcast Stations (550–1600 kc) are obtainable from the U. S. Government Printing Office and furnish detailed information on the classification and service areas of broadcast stations.

17–9. Standard A-M Broadcasting Antennas—In the Standard Broadcast Service operating between 550–1600 kc per second, antennas are usually of the metal tower type, either guyed or self-supporting. The height of the tower is related to the wave length as briefly explained in Section 17–3, which is to say the height is inversely related to frequency. Some broadcasting station antenna towers have a uniform cross section, whereas others are tapered or flared at the base. The shape of the tower determines the current distribution and consequently is a factor in determining the efficiency of the antenna as a radiator. The efficiency of the tower as a radiator is improved by keeping the maximum current high. Since a tower having a uniform cross section approximates a vertical wire antenna, its efficiency will be somewhat higher than a tower of the tapered or flared base type.

17–9a. Electrical height of vertical antennas—It is customary to refer to the physical height of a vertical broadcasting antenna in electrical degrees (360° equal one wave length). In the case of a quarter-wave (90°) antenna comprised of thin wire without supporting structure the electrical height is the same as the physical height. The physical height then is computed from

$$h \text{ (feet)} = \frac{246{,}000}{f}$$

where h = electrical height or actual physical height of a quarter-wave radiator in feet, assuming the waves travel at the velocity of light, and f = operating frequency in kilocycles.

When the antenna is more than just a thin wire, the cross section of the tower comes into consideration since the velocity of the wave traveling along the tower is decreased. Consequently, the electrical height may be greater than the actual physical height whether measured in degrees or in other units.

17–9b. Top Loading—It has been previously indicated that the center of capacitance of a vertical radiator and hence the point of maximum current can be raised by top loading in the form of a wheel or outrigger mounted on top of the antenna tower or additional top loading secured by adding wires extending from the wheel but insulated from the ground. Control of the amount of top loading can be achieved by inserting an inductance between the wheel and the tower. The practice of top loading antennas is generally resorted to when height is a limiting factor. In the case of an antenna less than a quarter wave in length (90°), utilization of top loading will increase the low-angle radiation efficiency.

The increase in efficiency of radiation results from the increase in the resistance at the base of the antenna and decreased capacitive reactance and consequent increase in field intensity. This results from the effects of top loading which as previously explained shifts the point of maximum current (current loop) upward on the antenna. The base resistance is increased and the inherent losses in the antenna system are minimized with a consequent increase in radiation resistance while the loss resistance remains the same.

As stated above, the capacitive reactance of the antenna is decreased when resorting to top loading; consequently, a smaller tuning coil can be used at the base to tune the system to resonance. The ability to utilize a smaller inductance at the base obviously reduces the resistance losses and more power goes into radiation.

17–9c. Series Loading—Another method of obtaining the advantages of a very high antenna with low-angle radiation without the dimensional disadvantages is by series loading. This is accomplished by providing two co-linear sections for the vertical radiator isolated from each other by means of an insulator across which a reactance is connected. This arrangement makes it possible to achieve, with a tower of given length, the anti-fading properties of a higher tower. By varying the reactance across the insulator a convenient means of varying the vertical polar pattern is obtained as well as permitting tuning the antenna.

If the top loading is accomplished by insertion of an inductance at a point halfway or more from the ground to the top the inductance must have an extremely high Q; otherwise the power losses in the inductance will offset the gain that might be achieved. An additional complication involves the mechanical difficulty of constructing a small lightweight, weatherproof inductance of sufficient Q capable of handling large values of r-f voltage and current. The lowest frequency for which a tower of given height can be used is limited either by the permissible voltage across the reactance or by the resulting reduction in radiation resistance.

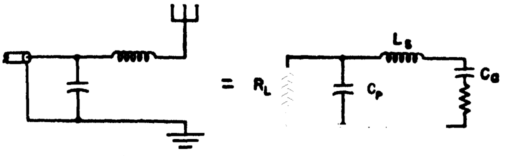
Instead of connecting an inductance across the sectionalizing insulator, the two conductors of a transmission line can be connected across the insulator with the other end of the transmission line brought to ground. At this end a reactance (inductance or capacitance) can be connected. The required value may be found by calculation or by experiment.

1. *Conveying Power to the Vicinity of the Antenna.* Since the modern 550–1600 kc broadcast transmitter is always located some distance from the vertical radiators to minimize losses and field distortions it becomes necessary to convey r-f power from the transmitter to the base of the radiator before it is possible to feed the radiator (antenna). The r-f line is always of the matched-impedance type, that is, it is operated without standing waves along the line, current and voltage being essentially constant along the entire length of the line. Therefore, the source (transmitter) and the load (antenna feed system) must both match the impedance

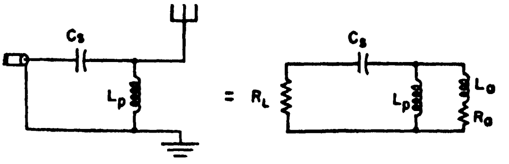
of the line. The line may be of open-wire type or (better) of the concentric type.

17-9d. Feeding Vertical Broadcast Antennas—Vertical antennas employed for standard broadcast operation are of two types: one in which the antenna tower is insulated from the earth by being supported on a base insulator, and the second where the antenna base rests on the ground and is tied-in with the ground system. In the former the antenna is excited by a series-fed system and the latter by a shunt-fed system. In the shunt-fed antenna, special precautions are taken to provide a good ground system in order to keep the circulating current losses low at the point where the system is energized by the transmitter.

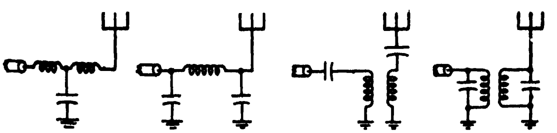
17-9e. Series-fed Antenna—Figure 17-7 shows several methods by which r-f power may be transferred from the transmitter via the r-f line to a series-fed antenna. In order to insure maximum transfer of power, the proper impedance match must be secured between transmission line and antenna.



(a) L-Coupling Section for a Short Antenna.



(b) L-Coupling Section for a Long Antenna.



(c) T-Section. (d) π-Section. (e) Series-Transformer Coupling Section. (f) Shunt-Transformer Coupling Section.

Fig. 17-7. Series-fed antenna-coupling networks.

This is done by appropriate choice of inductance and capacitance in the matching network so that the antenna impedance is transformed into a pure resistance equal to that of the transmission line.

The impedance between the tower and ground is an important consideration when series-feeding is employed and the design of the matching network is dependent on such a determination. The voltage developed across the base insulator depends upon the magnitude and power factor of this impedance and hence the power delivered to the antenna. In the quarter-wave antenna, the impedance (at the earth connection) approximates 37 ohms.[4] When the electrical length is a half wave, the base impedance is between 200 and 400 ohms, depending on the shape of the tower—having the lower figure when the tower has a wide tapered base.

17-9f. Lightning Protection—Since a series-fed antenna is insulated at its base, provision must be made for the removal of high voltages resulting from lightning bolts and static electric accumulations. Such protection is usually provided by ball or horn gaps across the base insulator. A choke coil is usually inserted in the lead to the antenna tuning and matching system to protect the r-f current ammeter. This meter can be protected from burn-outs, when local thunderstorms occur, by utilization of a double-pole, double-throw, make-before-break switch, permitting the removal of the meter from the circuit without interruption of the radio-frequency current. A degree of protection can be provided by a shunt across the meter but is of little avail in the case of a direct hit by lightning.

17-9g. The Shunt-fed Antenna—The shunt-fed antenna permits elimination of the base insulator. The exciting voltage is applied at a point on the antenna tower above ground in such a way that the lower section looks like a one-turn inductance comprising the antenna below the point of connection, the sloping feed line, and the ground return between the base of the antenna and the grounded outside conductor of the coaxial transmission line.

The point on the antenna tower where the single-wire line terminates is chosen so that the resistance component of the tower impedance is equal to the characteristic impedance of the transmission line. The impedance match is accomplished by a capacitance connected in series with the shunt-feed line because the loop comprising the shunt-feed line, the antenna, and the ground return path is inductive.

Since a shunt-fed antenna is directly grounded the amount of lightning protection equipment is reduced. Moreover, high-frequency antennas such as those employed for FM and television can be mounted on the top of the tower without the necessity of isolation-coupling equipment.

17-9h. Directional Broadcast Antennas—In the early part of this chapter it was stated that a single vertical antenna element operating over a perfectly conducting earth would propagate uniformly in all compass directions. In other words it has zero horizontal directivity and is sometimes referred to as an omni-directional or isotropic radiator. This is the performance desired in directivity when a station desires coverage in all directions. However, there are several considerations which make it desirable to install a directional antenna system. These considerations include:

(a) Increasing the field intensity in the direction of a densely populated area.

(b) An increase in power without increased sig-

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[4] For antennas having less than quarter-wave height, resonance must be secured by base-loading with an inductor; hence the voltage across the base insulators of the tower is increased greatly.

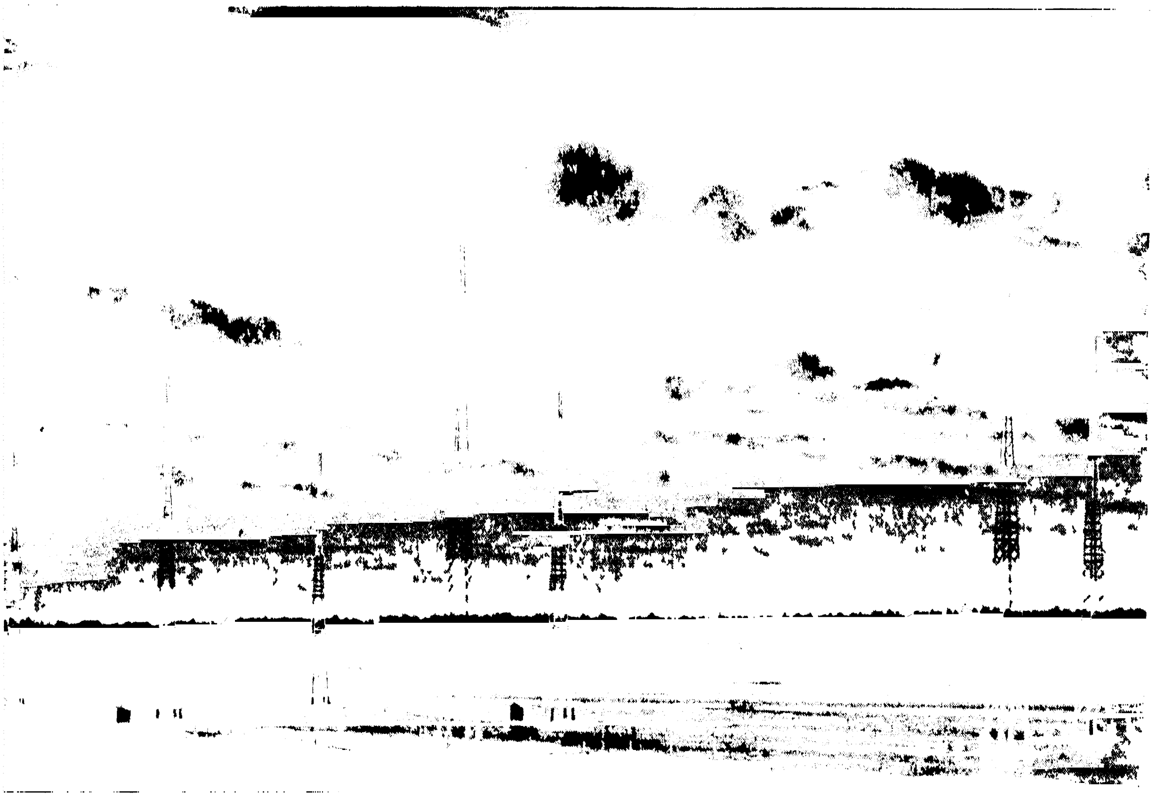


FIG 17-8 Seven element array antenna employed by WREX, Duluth, Minnesota.

nal in areas served by other stations on the same channel or adjacent channels.

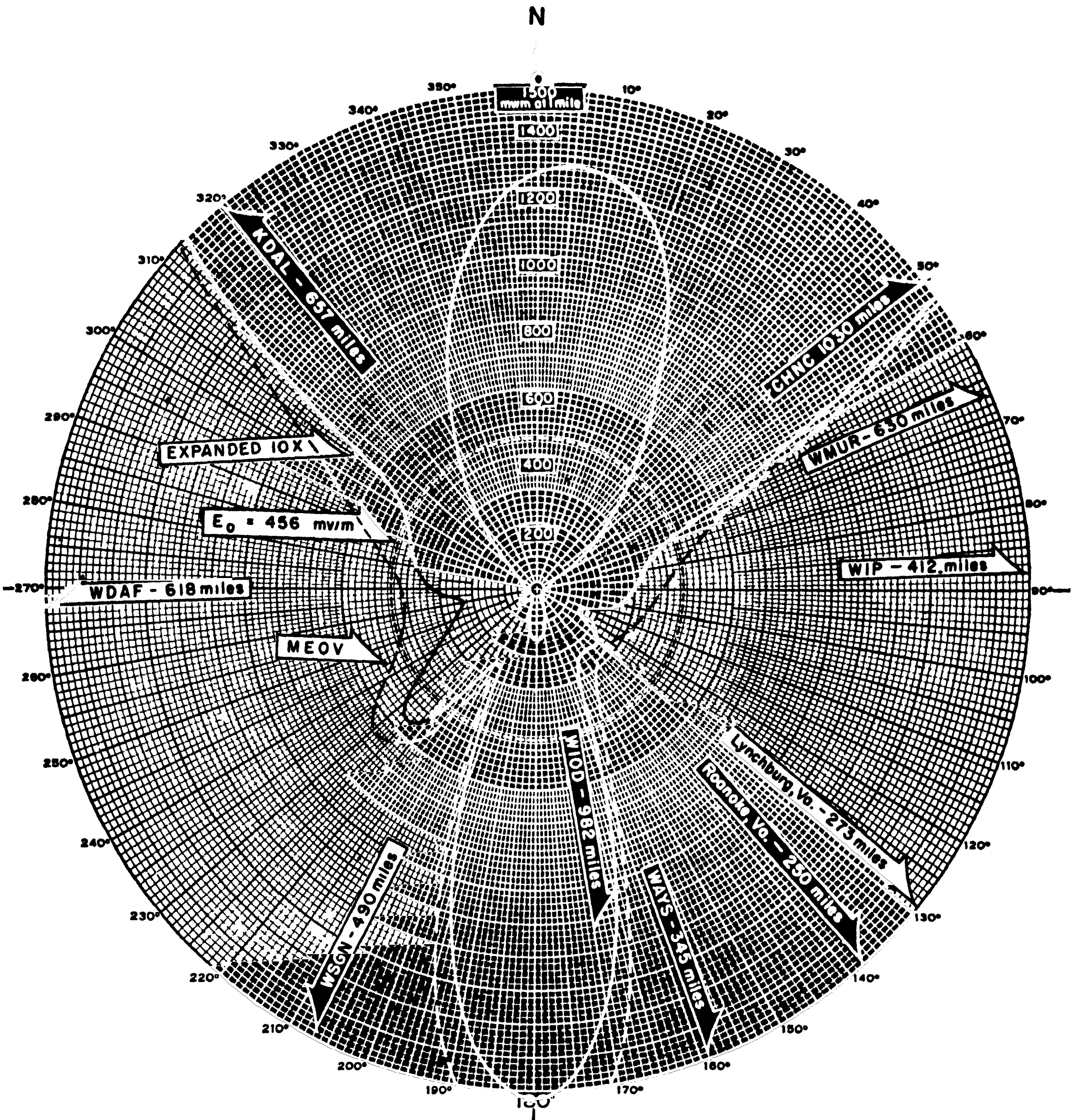
(c) Prevention of overlap of service areas in the case of multiple ownership.

17-9i. Directional Pattern Characteristics—The shape of the pattern desired for directional operation necessitates consideration of the area to be served and the protection to be given other stations. Economics make it desirable to achieve the shape of the pattern with the least number of antenna towers. Two towers can secure the desired results in some cases whereas from six to seven are required in others to provide the required nulls and lobes. Figure 17-8 shows a 7-element array employed by WREX, Duluth, Minnesota. Six elements are used for nighttime operation and three for daytime. Elements 1 to 6 are in the form of a parallelogram consisting of two rows of three each bearing 107.5° true (the six to the left in the photograph) as a nighttime array. End elements 1 and 2 of the parallelogram with an additional element 7, directly south of 2 (the one farthest to the right in the photograph) serve as a 3-element, triangular daytime array.

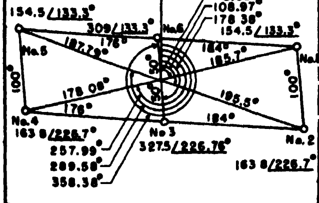
The field intensity at any given point is a function of the placement of the towers in the antenna array and the magnitude and phase of the field intensity radiated from each tower. In other words, its pattern shape is determined by the space configuration of the radiating elements and the vector sum of the field intensities produced by each radiating element.

Figure 17-9 illustrates a typical directional antenna design such as is presented to F C C. in the application for construction permit. It will be noted in this figure that the horizontal pattern along with an expanded scale for the low values of field intensity are presented. It is also desirable to present a curve showing the maximum expected operating value (MEOV). When making the proof of performance the directional antenna should be adjusted such that the unattenuated field intensity will not exceed this value. The stations to be protected and the root-mean-square (rms) circle are also presented on this chart. In addition to this information it is desirable to make a tower placement sketch, tabulate the pattern parameters and list pertinent station data. This information is very useful to anyone who has to investigate or deal with the directional antenna system.

17-9j. Feeder Systems for Directional Arrays—A more complicated feeder system is required in a directional broadcast array than that described previously for single-element radiators. (See Fig-



TOWER PLACEMENT SKETCH



PATTERN PARAMETERS

TOWER No	ELECTRICAL HEIGHT G°	TRUE TOWER ORIENTATION φ°	SPACING S°	PHASING ψ°	HORIZONTAL FIELD mvm E	FIELD RATIO F	ELEV. ANGLE θ°	ELEVATION RMS FIELD mvm Eθ
1	45	78 68	185.70	133 3	154 5	1 00	0	456
2	45	108.97	195 53	226.7	163 8	1.06	10	416
3	90	178 38	50 00	226 7	327.5	2.12	20	401
4	90	257 99	178.08	226.7	163 8	1.06	30	343
5	138	289 58	187 79	133 3	154 5	1.00	40	300
6	52	358 38	50 00	133 3	309.0	2.00	50	260
7							60	186
8							70	100
9							80	21
10							E0 = 340 mvm	
DAYTIME OPERATION ☐			NIGHTTIME OPERATION ☑				Pr = 5 kw	

STATION DATA

CALL	WHKC	
FREQUENCY	610	kc
POWER	5	kw
TIME OF OPERATION	U	
TYPE OF OPERATION	DA-N	
DAYTIME TOWERS	No. 5	
NIGHTTIME TOWERS	1,2,3,4,5,6	
No RADIALS PER TOWER	120	
LENGTH OF RADIALS	90° 400 ft.	
GROUND SCREEN DIMENSION		
LAT	39° 32' 26 2"	
LONG	82° 58' 36 1"	
SUPERSEDES	470423	
PATTERN No	470919	

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UNITED BROADCASTING COMPANY
CLEVELAND, OHIO

FIG. 17–9. Typical directional antenna design. (Courtesy United Broadcasting Company.)

ure 17-10.) Most directional arrays are of the base insulator, series-fed type. In general, a feeder system must perform the following functions:

(1) Present the proper load impedance to the transmitter by the matching network.

(2) Divide the output power of the transmitter properly between the antenna elements of the system so as to control the ratio of the magnitude of the field intensities radiated from each .tower.

(3) Control the phase of the field intensity vectors radiated from each tower.

(4) Transmit the power over the transmission lines from the transmitter to each element of the antenna array.

(5) Provide an impedance match between the transmission line and the antenna.

In some applications it may be desirable to combine the functions in such a manner that the matching, power dividing, and phasing can be controlled in a single network. On the other hand, more elements can be added by providing additional outputs from the power dividing network with appropriate feeder systems.

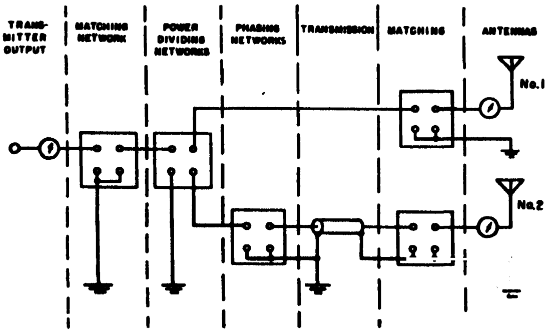

FIG. 17-10. Block diagram of a directional antenna feeder system.

17-9k. Current and Phase Meters—In the adjustment and operation of directional broadcast arrays it is essential to employ appropriate instruments to measure the phase difference between the currents in various towers of the array. The station license issued by F.C.C. generally specifies the input current and the ratio of the tower currents. The current ratios are obtained and maintained by proper division of the power while the input current is adjusted to the value stipulated in the instrument of authorization. The input current value is determined from input resistance measurements obtained by the substitution or variation methods. Radio-frequency bridges are also employed in making resistance measurements of antennas.

"Rules and Regulations" as well as "Standards of Good Engineering Practice" for Standard Broadcast Stations, established by the Federal Communications Commission, stipulate the characteristics of the radio-frequency current meters and tolerances within which the currents must be maintained.

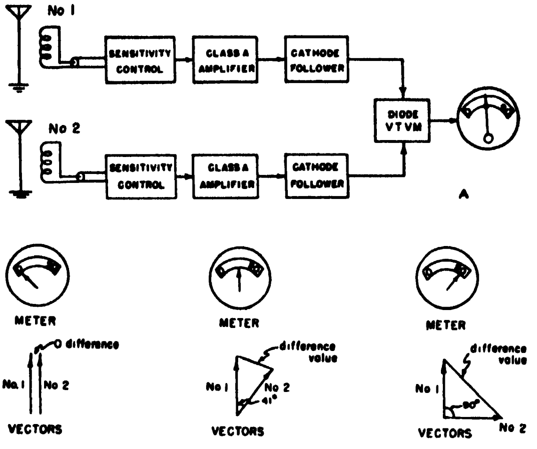

FIG. 17-11a. 0°-90° series connection.

To aid in monitoring the operations in case the towers are at some distance from the transmitter, remote reading of the antenna ammeters are obtained by inserting thermocouples directly in the antenna circuits with remote leads to a d-c current indicator in the transmitter building. Sometimes the thermocouple is inductively coupled to the antenna, thus eliminating the need for radio-frequency choke coils in the leads from the antenna if the thermocouple is connected directly in the antenna circuit.

In some instances automatic recorders are established for the purpose of insuring the maintenance of the authorized field intensity in given directions.

Figures 17-11a and 17-11b show two methods of connecting a phase monitor of the type manufactured by the Andrew Company and identified as type 40-C. The series connection is employed on the scale reading from 0° to 90° and the parallel connection from 90° to 180° for reasons given later.

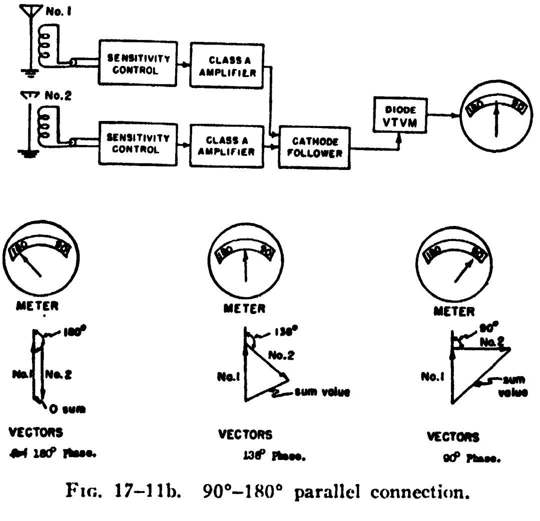

FIG. 17-11b. 90°-180° parallel connection.

17-10. Phase Monitors—Phase monitors are employed in tuning and maintaining the adjustments of directional antennas since it is necessary to have an instrument to measure the phase difference between the currents in the various elements of the array. There are several methods incorporated in commercial phase monitors employed for the purpose of measuring this phase difference.

Space does not permit a complete description of all commercial models but the following descriptions will aid in understanding the theory of operation.

17-11. Andrew Type 40-C Phase Monitor—The Andrew type 40-C phase monitor is an instrument designed primarily for use in adjustment and operation of directional antenna arrays at broadcast frequencies. It will measure phase difference and ratio of magnitude of currents. Provision is made for six inputs with suitable switching to allow rapid comparison of any two at a time.

The monitor is intended for use in the broadcast band, and has a sensitivity of less than one volt over that spectrum. The input impedance is approximately 72 ohms resistive, suitable for use with the 70-ohm coaxial cable commonly used for the line from the sampling loops to the monitor.

17-11a. Principle of Operation—The schematic in Figure 17-12 shows the 40-C monitor reduced to its most fundamental elements. If potentials P-1 and P-2 are in phase, they oppose each other and the meter reads zero. If they are out of phase, the total voltage applied to the diode is twice the magnitude of either one alone, and the meter reads full scale. The scale is calibrated in degrees, so that any phase angle may be read directly.

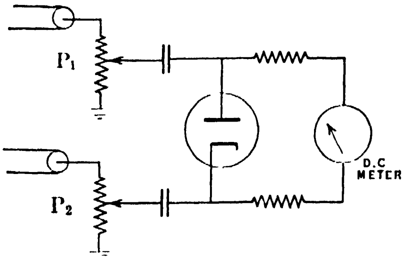

FIG. 17-12. Elementary circuit of Andrew type 40C phase monitor.

Since the diode circuit alone requires a signal of 20 volts, stabilized d-c and r-f amplifiers are provided to increase the sensitivity to 150 millivolts. The r-f amplifiers may be switched out to reduce the sensitivity to one volt.

From the above it can be seen that phase is measured by adjusting the two r-f voltages being compared to equal amplitude, mixing them, and impressing the resulting voltage on a diode rectifier. Since the magnitude of the resulting voltage varies as the time phase angle between them varies, the output voltage and current of the diode will also vary, and by properly calibrating a d-c instrument in the diode load circuit it is possible to read the phase difference of the two impressed voltages. The voltages can be added either in series or in parallel, and suitable meter scales can be provided to read phase difference. However, if either connection is used to read the entire range from 0° to 180°, the scale will be very crowded at one end or the other. The 40-C phase monitor therefore uses both connections and two scales: the series connection for 0° to 90°, and the parallel connection for 90° to 180°. This not only eliminates crowded scales and gives substantially linear calibration over the entire range, but provides a scale twice as long, allowing more accurate reading.

Each channel consists of a Class A linear amplifier with suitable input attenuator and selector circuits. In the 0°-90° connection (Figure 17-11a) a diode voltmeter circuit is connected across the outputs of the two channels.

It can be seen that the outputs are in series bucking; that is, if voltages of zero phase difference are impressed, the sum of the two voltages will be zero. The sum of out-of-phase voltages will give a resultant voltage that is read on the diode voltmeter. When the channel output voltages to ground are equal, the relative voltage (E) across the vacuum-tube voltmeter is given by the expression

$$E = e \sin \frac{\theta}{2}$$

where e is the output voltage to ground of either channel. This gives a scale that is substantially linear up to 90°, and therefore the calibrating point, or e, is chosen so that 90° are read at full scale.

In the case of the parallel connection (Figure 17-11b) the two channel output voltages are mixed at the output of the amplifiers.

It can be seen in this case that input voltages of 180° phase difference will give zero output voltage. Output voltage is expressed by the equation

$$E = e \cos \frac{\theta}{2}$$

This expression is approximately linear from 90° to 180°, which is the range of the second phase angle scale.

In addition to measuring phase difference, it is also necessary to determine which current (or voltage) is leading in time phase. This is accomplished by providing a "sense indicator," which is a pi network with a small phase delay characteristic (about 10°) which can be inserted in either input circuit. By noting how the phase readings increase and decrease, it can be determined which current is leading and which is lagging.

Current or voltage ratio is measured by using one amplifier channel feeding into the diode volt-

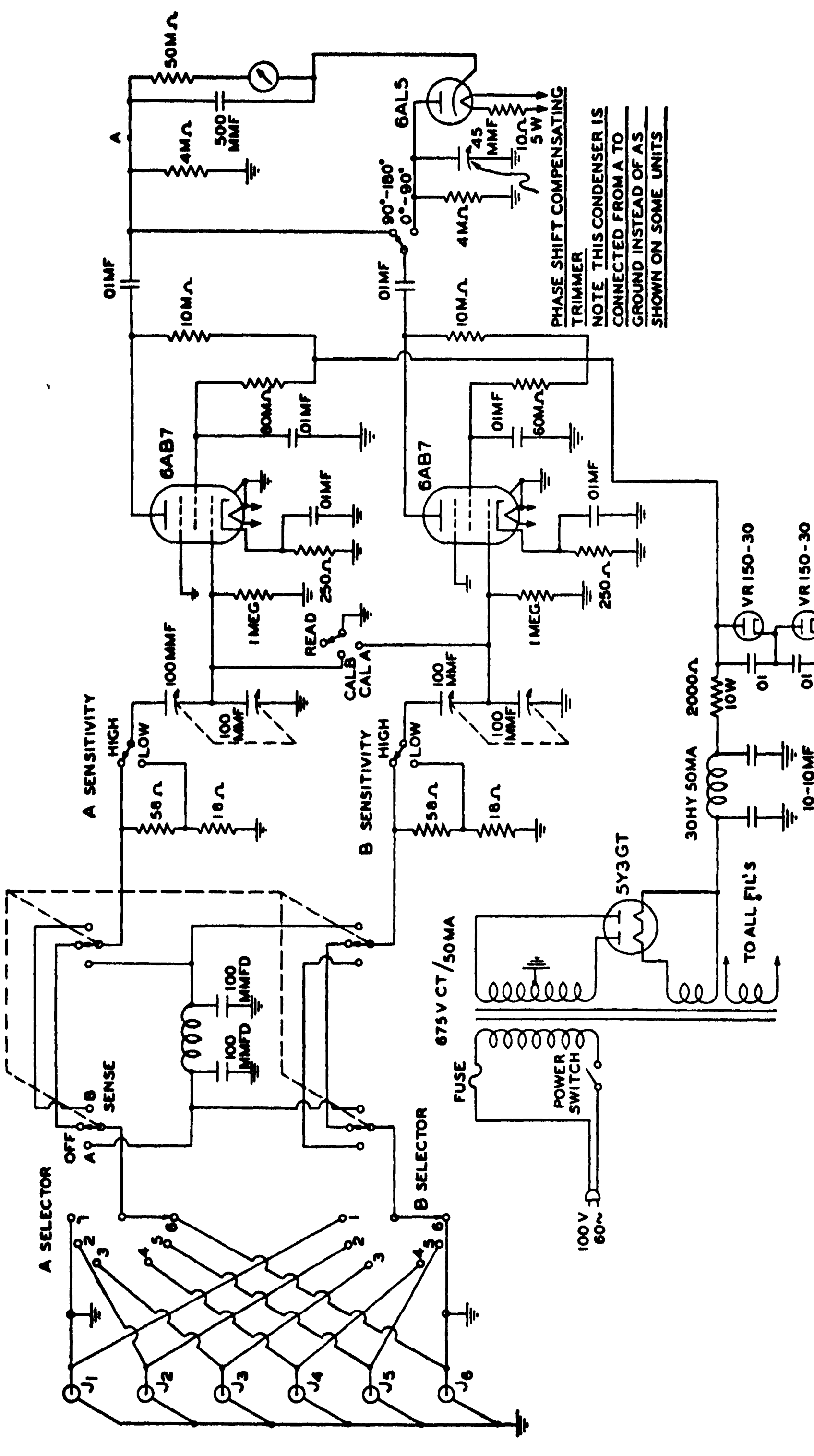

Fig 17-13 Phase monitor schematic of Andrew type 40C

meter. The attenuator of that channel is adjusted to give a reference output voltage. The amplifier input is then switched from the reference input to any other input desired, and the ratio read on the ratio scale. The complete schematic is given in Figure 17–13.

17–11b. Installation—The instrument is provided with a standard 10½-inch panel for relay rack mounting. The 110-volt, 60-cycle power feed is plugged into the power receptacle on the rear of the chassis. Coaxial cable receptacles J_1 to J_6 are provided at the rear of the chassis for the sampling lines.

It is recommended that the coaxial lines from the sampling loops or current transformers be the same length for all towers. While it is possible to measure the difference in phase shift in the lines due to difference in length it represents an additional factor that may introduce error.

17–11c. Operation—1. After allowing the instrument to warm up for several minutes, choose the two inputs to be measured by setting the A SELECTOR and B SELECTOR in the proper positions.

2. Place the two sensitivity switches in either high or low positions as required by the magnitudes of the input voltages, and the sense indicator in OFF position.

3. Set the RANGE switch in 0–90 or 90–180, as determined by previous experience. If the proper range is not known select either range and proceed with measurement. If the wrong scale has been chosen the meter will read off scale.

4. Set the CALIBRATING switch in CALIBRATE A position and adjust the A channel attenuator until the meter pointer is set on the red line (at 60° on the scale).

5. Set the CALIBRATING switch in CALIBRATE B position and repeat.

6. Set the CALIBRATING switch in READ position and read the phase difference on the proper scale.

7. Determine the SENSE of the two currents by means of the sense indicator. With the instrument in READ position set the SENSE INDICATOR in either channel. Knowing that the sense indicator introduces a phase lag, it is easy to determine which current is leading. For example, if a phase reading of 45° is obtained, and if, with the sense indicator set in channel A, the phase reading is 55°, it is evident that current A lags current B. If, on the other hand, insertion of the sense indicator gives a reading of 35°, then current A is leading current B.

17–11d. Measurement of Current Ratio—1. Set the RANGE switch to 0–90 position and the CALIBRATING switch to CALIBRATE A.

2. With the selector switch for channel A set on the reference input, vary the CHANNEL A ATTENUATOR to give a meter deflection of 1.0 on the current ratio scale.

3. Switch the CHANNEL A SELECTOR to select the input desired and read the ratio directly.

It is apparent that the magnitude of the reference input must be larger than that of the inputs being compared to it. Caution must be taken that the B SELECTOR is not set on either the reference or compared inputs, as this cuts the resistance of the line termination in half and will give erroneous readings.

17–11e. Operating and Maintenance Suggestions

1. Check the zero set of the meter occasionally, with no signal input. It will be observed that a false zero is provided on the meter scale. This is to compensate for the no signal space current of the diode rectifier. The zero set must of course, be made with the instrument turned on. Different diodes have different values of space current, so in some cases with the instrument calibrated to "0" on the scale, the needle will not return to the zero current mark on the scale. This has no effect whatever on the performance of the instrument.

2. Tap the meter case lightly when making measurements. The meter movement is a 0–50 d-c microammeter, and internal friction may produce slight sluggishness.

3. It is necessary to compensate the monitor for unequal phase shift through the two channels due to different tube interelectrode capacitances, lead capacitances, etc. The adjustments are normally made at the factory for proper operation at the frequency for which the unit is ordered, but they can be done in the field if necessary. They should be made if the operating frequency of the instrument is changed.

Supply signal with a small phase difference, say 30° to the input of the two channels. Adjust the diode trimmer for equal readings as the channel selector switches are reversed. This equality of readings should then hold over the entire range of the instrument.

Voltages out of phase can be obtained by using cables of different length to feed the two channels.

4. The sense indicator circuit has been adjusted at the factory, and should not require any readjustment. If, for any reason, it becomes necessary to readjust the circuit, it should be done by means of an r-f impedance bridge. Connect the bridge to the input grid of either Class A amplifier and with the sense indicator in off position measure the r-f impedance looking back towards the input. Then insert the phase delay network in the circuit and adjust the coil until the r-f impedance measures the same as it did without the sense indicator in the circuit.

5. Receptacles J_1 to J_6 are intended for use with solid dielectric cable and suitable connectors. RG 11/U is the proper cable type. The splice or connection between rigid sampling line and solid dieelectric cable should be within 10 feet of the phase monitor and the lengths of solid dielectric cable should be identical.

17-11f. Specifications

Frequency range: 500 to 1600 kc.
Current ratio range: 0.1 to 1.
Phase angle range: 0° to 360°.
Accuracy, phase angle measurements: ± 2°.
Input impedance: 72 ohms.
Sensitivity: 0.75 volt.
Maximum permissible signal: 15 volts.
Power supply: 115-V, 60 cycles.
Power consumption: 50 watts.

17-12. RCA Type 300-C Phase Monitor—Figure 17-14 shows the schematic of the RCA type 300C phase monitor. In this monitor a cathode-ray tube is employed to provide visual indication of the phase relationship of the antenna elements. When the currents in the antenna elements are in phase, the initial elliptical pattern on the face of the cathode-ray tube becomes a straight line.

17-12a. Circuits—The remote antenna meters are connected in series with the sampling line, and the sum of the meter resistance and a series resistance makes up the terminating resistance for the line. The combination is somewhat affected by the input circuit of the phase circuits, but is corrected so the proper terminating resistance (77 ohms) is obtained.

A variable shunt resistance is connected across each indicating meter; this circuit provides a means for adjusting and maintaining a proper relation between the line current indication and the value of the remote antenna current.

The shunt range on the rheostat is limited, hence adjustment of the meter indication does not become critical, and can easily be made. The input to the phase measuring circuits is taken directly across the sampling line, and terminates from both selector switches. As the input potentiometers are switched from one line to another, a load substitution is made, thereby maintaining constant loading on the line.

From the input potentiometers, two amplifier channels are used to deflect the cathode-ray tube electron stream. The "X" amplifier is so labeled, because it deflects the beam horizontally, and the "Y" amplifier so marked, because it gives the vertical deflection.

In the "X" amplifier channel, for the first stage, a vacuum tube is used in a phase shifting network, after which both channels are alike.

The phase shifting network consists of a pentode tube, triode connected, having an unbypassed cathode as is used for inverter service. The plate load is essentially capacitive reactive, hence produces a phase shift of approximately 90° from that which normally appears in the plate circuit of a tube loaded with resistance. A potentiometer (R32) connected between the plate and cathode provides a continuously variable phase shift in voltage over an approximate 90° range.

In order to maintain the proper capacitive reactance in the plate circuit over the frequency range of the instrument, the plate condenser is made variable.

Three fixed ranges are used, with a variable air condenser to give variable capacitance between the ranges. Once the condenser is set for a given frequency, it needs no further readjustment, since the voltage appearing in the cathode and plate circuits is independent of the condition of the tube.

Two-stage amplifiers are used to drive the cathode-ray tube. Plate inductances, which are adjustable, make the phase shift of both amplifiers alike. A small variable capacitor in one amplifier is sufficient to maintain identical phase shift through the amplifiers at all frequencies within the range of the instrument.

A resistance connected in the common plate supply lead to both output amplifiers, and common to both, provides phase compensation of the cathode-ray tube, since a small amount of capacitance exists between the vertical and horizontal deflecting plates due to the leads leading to those plates.

A third, or blanking amplifier, connected to the plate of the first stage of the vertical amplifier, applies a blanking signal to the grid of the cathode-ray tube, when the push-button is depressed.

The blanking amplifier is so connected that the phase relationship of blanking signal provides the means of indicating the proper quadrant, and, hence, the proper scale to be read. When the scale-shift switch is changed in position, the blanking amplifier signal-phase is shifted to a different scale. At the same time, both amplifiers are reversed, with respect to their line connections. One switch is labeled PHASE SHIFT; therefore, less confusion arises in phase measurements. Hence, there should never be any doubt as to which scale should be read. Since quite high voltages exist in the instrument, a safety switch is supplied, which opens as soon as the cover is removed.

17-12b. Operation—Turn on the power switch, set the X and Y gain controls at minimum, and place the INTENSITY control at approximately mid-position. When a spot appears on the cathode-ray tube, this may be focused with the FOCUS control. A sharply defined spot should appear.

Do not allow the trace to remain on the tube screen for long periods. If a small intense spot is allowed to remain in a fixed position, for even a short time, burning may result. This does not affect the operation of the cathode-ray tube, except it may cause dead spots or insensitive portions of the tube screen.

A change in gain setting during measurements will introduce a small error in readings, because of phase shift in the gain control circuit.

If the spot does not appear in the center of the screen, it may be centered by means of the HORIZONTAL and VERTICAL centering controls, which are

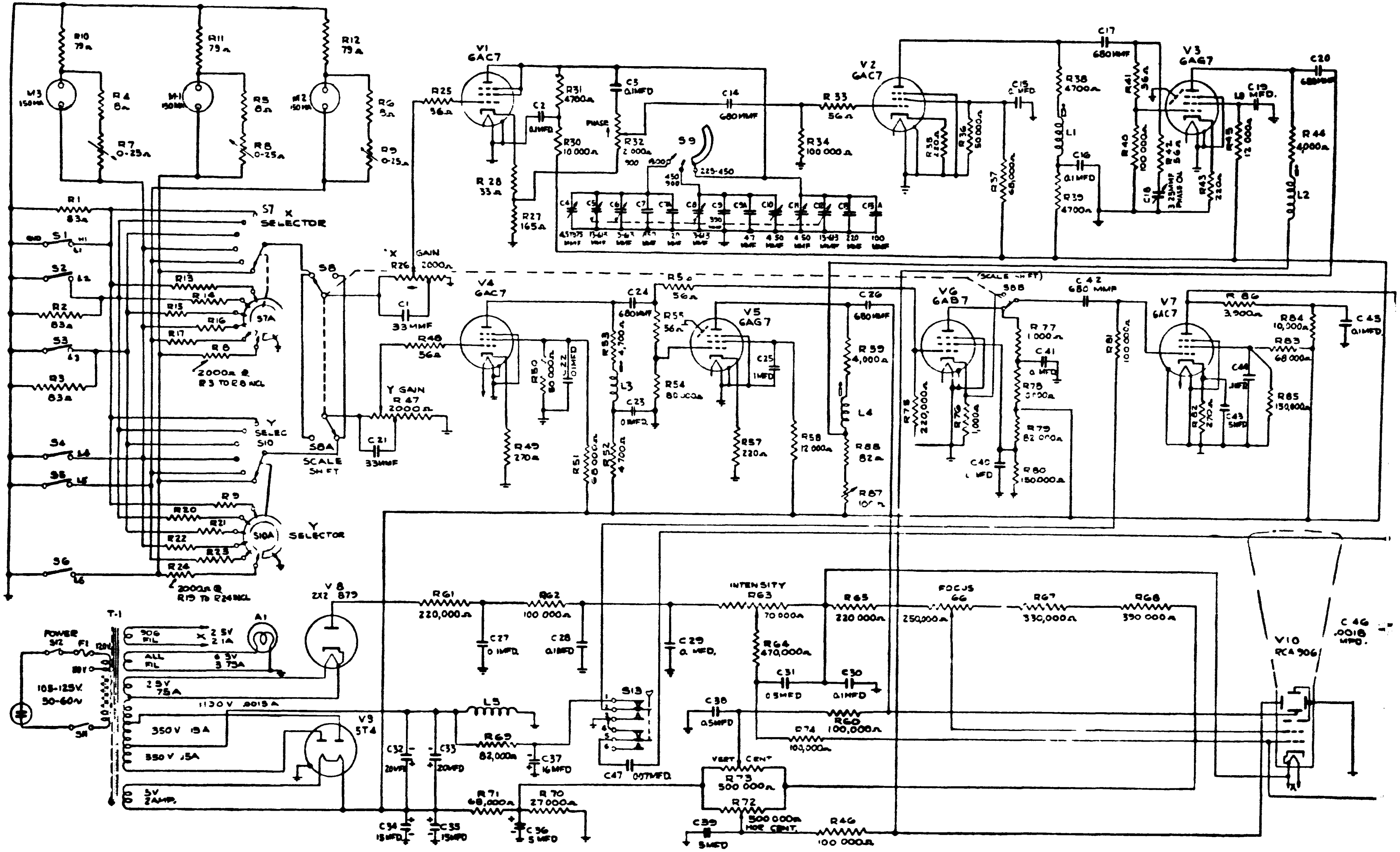

Fig. 17–14. Phase monitor RCA type 300C.

located within the space behind the door at the lower portion of the panel.

Set each of the selector switches "X" and "Y" to the same line (A_1) designation, etc. (preferably the line with highest current), and set the main phase dial at zero degrees (maximum left position). Increase the setting of the gain controls so a trace at approximately 45 degrees appears on the screen. If the pattern appears as an ellipse, this should be corrected with the PHASE CAL. control also located within the compartment with the centering controls.

Adjust the PHASE CAL. control for a straight line pattern of minimum width.

Change the selector switches (X and Y) to the lines between which the phase shift is to be measured.

The "X" selector switch is always used as the reference. Thus if the phase relationship between the currents in tower A, with respect to B, is to be measured, then A is the reference and the "X" selector should be set on A_1, and the "Y" selector switch set on B_1. Since the measurement is made in terms of "X" leading "Y," proper choice of switch setting would indicate that the current in the tower indicated on the "X" selector leads the current in the tower indicated by the "Y" selector by the angle indicated when the balance is complete.

Rotate the phase control until a closed pattern is again obtained. If this cannot be done, rotate the PHASE SHIFT control to its opposite position. Rotation of the PHASE CONTROL should then close the pattern.

The indication obtained is then the leading phase angle between the element connected to the "X" selector and that connected to the "Y" selector.

In order to determine the proper scale to be read, press the push button. A portion of the trace will disappear and the remaining trace will point in the direction of the scale to be read.

Each pair of numbers governs its scale over that 90-degree section of the cathode-ray tube; hence, the slope of the trace on the cathode-ray tube screen may vary from a nearly horizontal pattern to a nearly vertical pattern, and still indicate a definite quadrant or scale reading. Each quadrant is covered by that area divided by an imaginary vertical and horizontal line through the center of the cathode-ray tube.

Unless the amplitudes of the voltages on the "X" and "Y" channels differ very widely, there is no doubt which quadrant is to be read.

Usually in an antenna array, the currents do not vary to the extent that the balanced trace is so near horizontal or vertical that it is difficult to determine the quadrant.

For the best accuracy; especially at frequencies above 1,000 kc, the initial balance with both channels on a single line, should be made on that setting for "X" and "Y" switch positions. The gain controls should not be disturbed during a series of measurements.

Note: High-frequency monitoring is discussed later in the chapter.

17-13. Power Gain—When making determinations of the efficiency of antenna, engineers employ the terms "power gain" and "field gain." In making comparisons, the field intensity of a half-wave antenna in free space at a distance of one mile is frequently used as a standard of reference. "Free space field intensity" is defined as the field intensity that would exist at a point in the absence of waves reflected from the earth or other reflecting objects. The "power gain" is defined as the ratio of the powers that would be required to give the same field strength at a point one mile distant. In other words, the power gain is the increased power (expressed as a ratio) that would be required to feed the half-wave antenna to obtain the same increase in field strength as obtained with the multi-element antenna. Thus,

$$\text{Power gain} = \frac{\text{power required with vertical half-wave antenna}}{\text{power required with multi-element antenna}}$$

In many organizations the power gain is expressed in decibels.

17-14. Antenna Field Gain—Antenna field gain, as defined in the Federal Communications Commissions rules, is as follows: "The term 'antenna field gain' of a high-frequency broadcast antenna means the ratio of the effective free space field intensity produced at one mile in the horizontal plane (vertical antenna radiating waves vertically polarized) expressed in millivolts per meter for 1 kilowatt antenna input power to 137.6." As stated previously "free space field intensity" means the field intensity that would exist at a point in the absence of waves reflected from the earth or of other reflecting objects. Therefore, the field gain of any multi-element antenna expressed as a ratio:

$$\text{Field gain} = \frac{\text{field intensity of antenna for 1-kw input}}{\text{137.6 millivolts per meter}}$$

17-15. Relationship between "Field Gain" and "Power Gain"—The increase in field intensity for a given antenna at any point is equal to the square root of the increase in power, or

$$\text{Field gain} = \sqrt{\text{power gain}}$$

Thus it can be seen that if one desired to double the signal intensity it would be necessary to increase the power four times. Obviously, if the effective power can be increased by the use of a multi-element antenna, definite savings will result in initial cost of equipment and operating costs.

17-16. Field Strength Measurements—There are two basic methods of measuring the intensity of radio signals—one is identified as the *standard-antenna method* and the other the *standard-field method.* In the first method the voltage produced in a standard antenna by the field to be measured and computing the radio field intensity from the measured voltage and the dimensions and form of the standard antenna.

17–16a. Unit of Measurement—The universally adopted unit of measurement for field intensity is "volts-per-meter." The unit volts-per-meter is a large one and for all practical purposes it is more convenient to use the term millivolt-per-meter or microvolt-per-meter (μv/m). A field strength of 1 millivolt-per-meter means that the potential difference induced by the field between two points a meter apart on the same line of electric force is 1 millivolt (1/1000 volt). Consequently, if a 1-kw transmitter produces a field intensity of 20 millivolts per meter at a distance of 5 miles and is received on an antenna having an effective height of 5 meters, there will be 100 millivolts of signal induced in the antenna and available at the receiver terminals, neglecting the Q of the antenna, losses in the lead-in, etc.

17–16b. Standard-antenna Method—In the standard field method the voltage produced in an antenna by the field to be measured is compared with a standard field. The measuring equipment for the two methods are of the same general form. In the case of the standard-antenna method special requirements for the receiving antenna and voltage-measuring equipment are necessary. In making measurements to determine the coverage or performance of a standard broadcast antenna or array the standard-antenna method is employed. A loop antenna is used generally in association with a double detection receiver having a vacuum-tube voltmeter connected in the output of the second detector as shown in Figure 17–15.

The method of coupling the standard antenna to the voltage or field strenth measuring set is generally such that the voltage measured is not the voltage produced in the antenna by the field but bears a fixed ratio to it. This ratio is called the voltage-transfer ratio. The magnitude of this voltage ratio is dependent upon the point of introduction of the calibrating voltage into the measuring circuit. A standard voltage source is provided and included as part of the field intensity measuring equipment.

Vertical and horizontal half-wave dipoles are also used in place of a loop antenna and are particularly convenient when making measurements above 30 mc.

17–16c. Standard-field Method—The standard-field method of radio field intensity measurements consists of setting up a known field at the receiving antenna by employing a low power oscillator or transmitter as the signal source. The field at the receiving antenna is computed from the dimensions of the transmitting antenna, its current and current distribution, the distance, and the effect of the ground taking into account the elevations of the transmitting and receiving antennas.

The local transmitter generally employs a loop antenna, because of the ease in computing its radiation. At frequencies above about 40 mc an open vertical antenna may be used.

17–16d. Automatic Field Intensity Recordings—Automatic recording of field intensity as well as atmospheric noise is used to advantage in accumulating data in connection with radio wave propagation studies and frequency allocations.

A method in general use employs a conventional receiver having good stability of frequency and the recorder is connected in the plate circuit of one or more of the tubes under automatic volume control. A substantial logarithmic relation between the recorder deflection and the radio field intensity may be obtained and is convenient in view of the great time variation of field intensities often encountered.

The choice of the time constant is dependent upon the ultimate use to be made of the measured data.

Generally, a vertical antenna whose effective height has been determined is connected to the receiver associated with the automatic recorder. Calibration of the recorder is made from time to time by using a signal generator connected to the receiver through a dummy antenna having the same constants of the receiving antenna.

17–16e. Accuracy of Measurements—This text is not designed to go into the details of field intensity and automatic field intensity recordings, particularly with respect to the precautions that are necessary in regard to the qualifications of those engaged in the project, the choice and performance of equipment, number of measurements, choice of locations at which measurements are made, weather

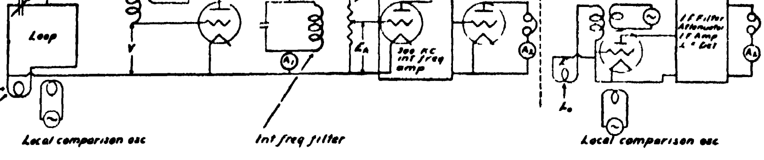

FIG. 17–15. Diagram of field strength measuring apparatus.

conditions and the analysis and evaluation of results. Measurements made at frequencies below 3 mc under ideal conditions can be made with an accuracy of about 5 percent and under usual operating conditions the accuracies may not be better than 10 percent. These estimates are for a range of field intensities from about 100 microvolts per meter to about 1 volt per meter.

There are many publications available from both the Institute of Radio Engineers and from the Government that are devoted to the above subjects.

17-17. Ungrounded High-frequency Antennas—The most common type of high-frequency antenna is that shown in Figure 17-16. It is similar to the antenna employed by Hertz in his early experiments. Its modern version consists of a wire in space, one-half of a wave length long and resonant at a wave length approximately 2.08 times the length of the wire in meters. The half-wave Hertz antenna is often referred to as a dipole or doublet. These terms are used synonymously in this text. It may be used as either a vertical or horizontal radiator. A radio-frequency wave exciting such an antenna travels to one end of the antenna wire and is reflected back toward the center. The reflected wave meets the next incident wave and the voltage and the current at any point along the antenna wire are the algebraic sum of the two waves. The result is a distribution of current and voltage along the antenna as depicted in Figure 17-16. At the center we find a current loop and a voltage node and at the ends voltage loops and current nodes. The voltages at the two ends are 180° out of phase and, consequently, of opposite polarity. The curve representing the distribution of voltage and current, as shown in Figure 17-16, represents a standing wave on the antenna. If the current and voltage were uniform throughout the length of the antenna it would indicate the absence of a standing wave. This condition would result if the energy were absorbed from one end of the antenna at exactly the same rate it is supplied at the other.

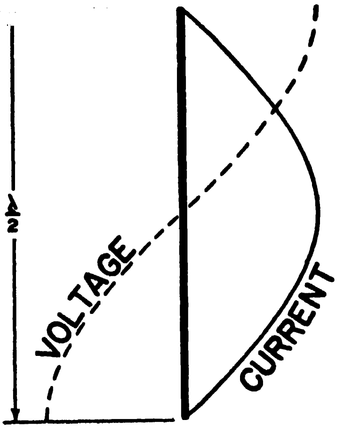

FIG. 17-16. Distribution of current and voltage on a half-wave Hertz antenna or doublet.

17-18. Resonant Frequency and Electrical Length—An antenna in free space would have its physical length equal to its electrical length. In other words, a full-wave 20-meter antenna would be 20 meters long, and a half-wave antenna, 10 meters long. However, since the presence of the earth and near-by objects influence the electrical length of an antenna by reducing the velocity of propagation along the conductor, a correction factor must be used to determine the correct physical length.

The physical length of a practical half-wave antenna is determined approximately from the following formula:

$$L = \frac{492 \times 0.95}{f} = \frac{468}{f}$$

where L is the length in feet and f the frequency in kilocycles.

17-18a. Frequency Response Characteristics—The resonant frequency of a simple dipole or doublet is quite narrow. The simplest way of accomplishing a wide band response, such as required for television, is to employ a folded doublet of the type shown in Figure 17-17. For receiving or very low power transmission, such a folded doublet like that in the upper part of Figure 17-17, may be made of commercially available 300-ohm transmission line with polyethylene insulation between the conductors. It is cut to the proper length and short-circuited at both ends. One of the two conductors is then cut at its center and a 300-ohm feed line of the same type connected to the cut ends.

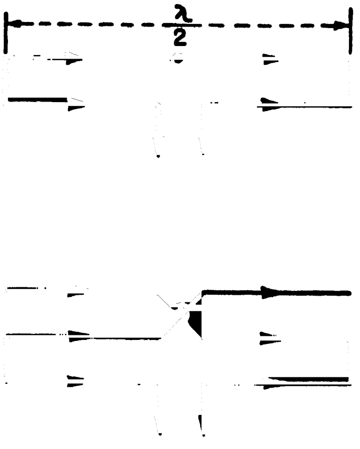

FIG. 17-17. Folded doublets.

The spacing between the elements of a folded doublet compared to their diameter has considerable effect upon the bandwidth characteristics of the antenna. The larger the diameter of the elements the wider the bandwidth. The theoretical limit of the spacing is somewhat less than an eighth of a wave length.

It has been predicted mathematically and proved by experimentation that the bandwidth response of a single dipole can be increased by increasing the element length slightly over a quarter wave length, thereby causing the antenna to become inductive, and then cancelling this inductance with the capacitance formed by overlapping the inside ends a slight amount.

Another expedient for increasing the bandwidth is to increase the diameter of the conductors and sometimes to make them of a shape other than cylindrical. Forms which have been used are two identical cones tip to tip, a narrow cone and a wide one, tip to tip, a cone and a disc. These shapes are not continuous surfaces in all cases. There are many other variations, some of which have seen use in television transmission and reception and are for that reason described briefly later in this chapter.

17-19. Radiation Characteristics of the Half-wave Ungrounded Antenna—The radiation pattern of a half-wave antenna is in the form of a doughnut with the diameter of its hole reduced to zero, as shown in Figure 17-18. If the antenna is erected vertically the electric waves will be vertically polarized and their strength in a horizontal plane will be equal in all directions. The polar diagram of the vertical antenna is shown as *a* in Figure 17-18, with equal field strength in all directions as in *b*. If the same antenna is erected horizontally, as shown in Figure 17-19, the waves will be horizontally polarized. There will be no substantial radiation along the axis of the antenna and maximum radiation at right angles to the antenna with the distribution as shown in Figure 17-19b. Referring to the polar diagram of the horizontal antenna as shown in Figure 17-19(b), it will be noted that the field strength is not uniform in all directions but maximum at right angles to the antenna; falling off as a cosine function resulting in a field strength pattern in the form of a figure eight.

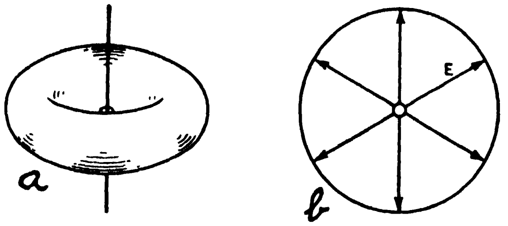

FIG. 17-18. Radiation pattern from a vertical half-wave antenna placed some distance above ground.

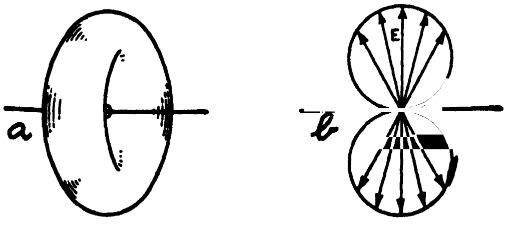

FIG. 17-19. Radiation pattern from a horizontal half-wave antenna far above the earth.

The antenna of Figure 17-19 is said to have directivity, since it transmits more energy in some directions than in others. In fact it is bidirectional, since there are two major lobes of radiation at right angles to the plane of the antenna. Since a directional characteristic is undesirable when uniform coverage is desired, it is possible to employ two horizontal antennas crossed at right angles and fed in quadrature (in phase); consequently, the field pattern of one antenna of a pair falls in the area of low radiation of the other antenna, resulting in the production of a combined field pattern approaching the form of a circle, with a radius equal to the diameter of the individual circles shown in Figure 17-20. Such an antenna is said to be omnidirectional. Since the power from the transmitter divides equally between the antennas of the crossed pair (one-half of the power goes into each antenna), the radiated power in the horizontal plane from the pair is only half that of the single vertical antenna and the field strength is approximately 71 percent of that of b in Figure 17-18. The radiation in the horizontal plane, however, can be increased and that in other directions decreased by mounting two or more in-phase antennas one above the other, along a common vertical axis. Each of the antennas then contributes to the radiation in the horizontal plane and their combined effect decreases the power radiated in other directions and, consequently, the doughnut is flattened out and increased in diameter, as in Figure 17-21.

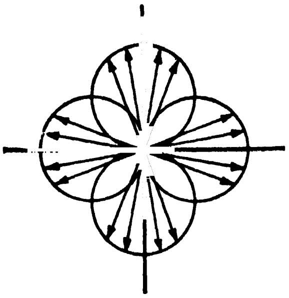

FIG. 17-20. Radiation pattern in a horizontal plane of two crossed half-wave antennas.

17-20. Harmonic Excitation of an Ungrounded Antenna—The lowest frequency at which an antenna of any type (grounded or ungrounded) resonates is called its fundamental frequency and the corresponding wave length is the fundamental wave length. It is possible to excite an antenna so that it has two or more standing waves on it; it is then resonant at approximately an integral harmonic of the fundamental frequency, the fundamental

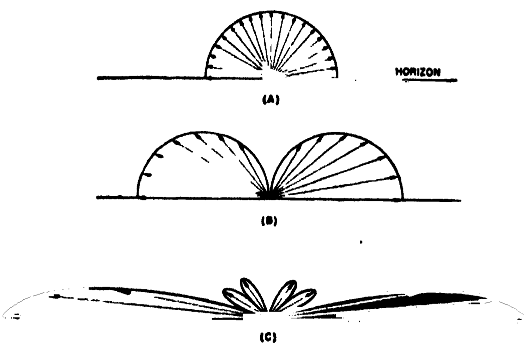

FIG. 17–21. Radiation patterns from (a) single layer, (b) two-layer and (c) six-layer antennas show how antenna gain is achieved by squashing down the radiated energy, thereby increasing the signal along horizontal.

being referred to as the first harmonic. A full-wave ungrounded antenna (two half waves) operates on the second harmonic. When excited at an odd harmonic such as the third, the ungrounded antenna is electrically 1½ wave lengths long. The resultant radiation from an harmonically operated antenna at any particular angle and horizontal bearing is determined by adding the effects of all the individual elements of the antenna at that angle and bearing. The current and voltages in the antenna elements differ in amplitude and phase, resulting in a difference in the electric fields produced in various directions.

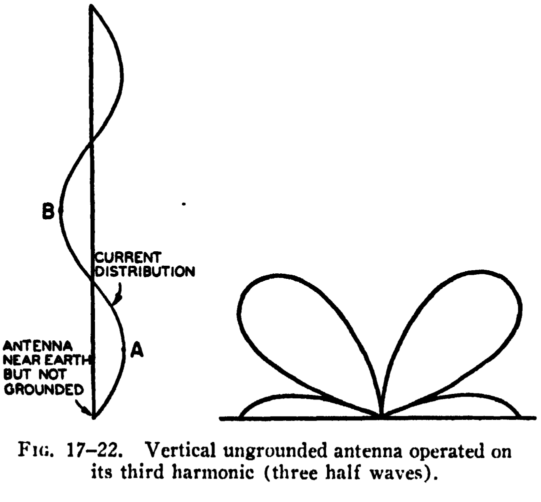

FIG. 17–22. Vertical ungrounded antenna operated on its third harmonic (three half waves).

Consider now a vertical *ungrounded* antenna operated at its third harmonic. It will have three standing waves on it, as shown in Figure 17–22. The currents at points A and B are 180° out of phase, so that when maximum current is flowing up the antenna past point A, maximum current is flowing down the antenna past point B. Consequently, the radiation fields produced by the half-wave element at A and B are likewise 180° out of phase and at any point an equal distance in space from A and B they oppose each other. The polar pattern showing the characteristics of the radiation field is shown at the right of Figure 17–22. It should be noted that in addition to the low angle of radiation there results a high-angle lobe of radiation having directive properties. The horizontal pattern of radiation from such an antenna when placed horizontally is shown in Figure 17–23a and that for two wave lengths in Figure 17–23b.

17–21. Feeding the High-frequency Antenna—There are two methods generally employed for feeding power to the high-frequency radiating system. These are commonly known as the current-feed or low impedance and the voltage-feed or high impedance systems. The distinction is a somewhat forced one, but may be explained as follows. In the low impedance or current-feed scheme, the power is introduced into the antenna at or near a current maximum, that is, at or near a voltage node. This is a point of low impedance, hence the transmission line "sees" a low impedance (mostly resistive). If the line is of high impedance, an r-f matching transformer or network is needed. In the high impedance or voltage-feed scheme, the feed is at or near a current node, that is, a voltage maximum point. The feed device "sees" a high impedance.

There is nothing to prevent feeding at any intermediate point and it has been done many times. An impedance match must always be obtained to insure the desired transfer of power as described previously in the case of the standard broadcast vertical antenna.

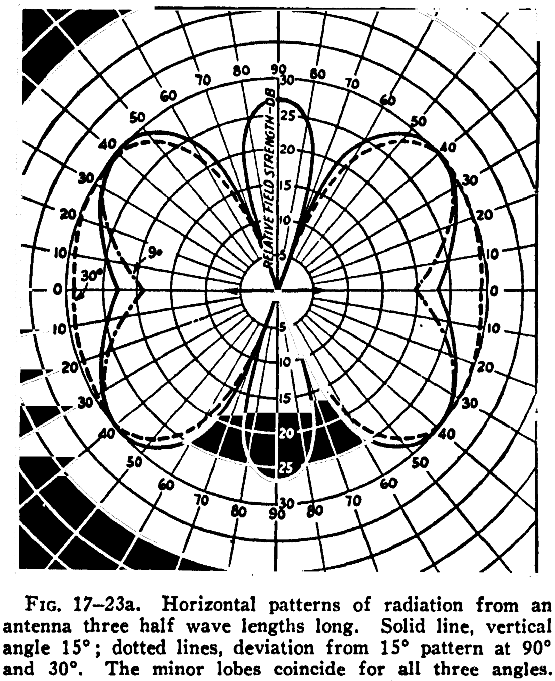

FIG. 17–23a. Horizontal patterns of radiation from an antenna three half wave lengths long. Solid line, vertical angle 15°; dotted lines, deviation from 15° pattern at 90° and 30°. The minor lobes coincide for all three angles. (Courtesy American Radio Relay League.)

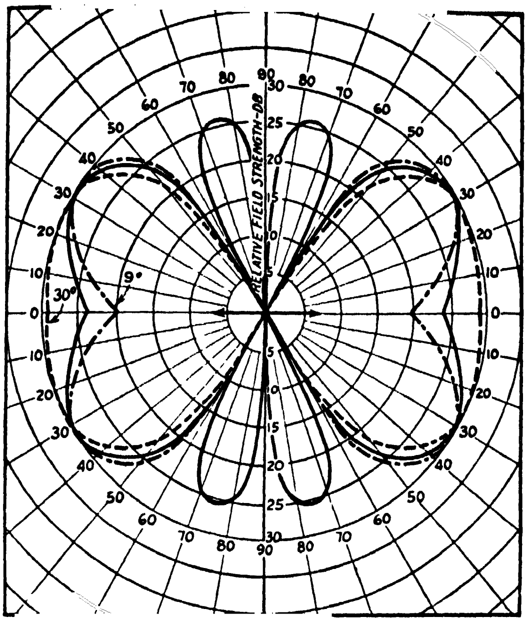

FIG. 17–23b. Horizontal patterns of radiation from an elevated horizontal antenna two wave lengths long. Solid line, vertical angle 15°; dotted lines, deviation from 15° pattern at 90° and 30°. The minor lobes coincide for all three angles. (Courtesy American Radio Relay League.)

One of the simplest methods of supplying power to a grounded antenna is to extend a lead-in from the antenna to the transmitter, inductively coupling a few turns to the final amplifier and then continuing to a good ground system. In such a case the lead-in, as well as the antenna, forms the radiating system. The antenna, in this case, can be tuned to resonance by inserting an inductance, a capacitance, or a combination of both in the lead-in. The tuning and coupling are adjusted until the desired transfer of power is obtained. Such a system is, however, generally confined to low and intermediate frequency installations.

17–22. Transmission Lines—It is desirable to place a high-frequency antenna as high and as clear as possible. It is then necessary to employ a transmission line to transfer power from the transmitter to the antenna. If the antenna is to be energized at a point of low impedance a current-feed system must be employed, and a voltage-feed system if fed at a point of high impedance.

The transmission line generally consists of either a single wire or a pair of wires such as twisted pair, shielded pair, spaced open wires, or a concentric or coaxial line. The latter is but a single conductor inside a tube from which it is insulated by spacers in the form of rings. The tube is the other conductor. Flexible coaxial cable is made by using rubber or plastic dielectric for maintenance of spacing of the inner conductor and employing braided or other flexible metal shielding as the other conductor.

In the case of open two-wire lines, the electric and magnetic fields extend into space. This effect produces radiation losses when sending and, when employed for reception, picks up noise and interference. In a coaxial line, however, no electric or magnetic fields extend outside the outer conductor, all fields existing in the space between the two conductors, provided the line is properly terminated. A perfectly shielded line results. While the losses for a given length are lower than for twisted or shielded pair, concentric line is more expensive and must be kept dry inside. To prevent condensation of moisture, coaxial lines are frequently filled with dry nitrogen at pressures ranging from 3 to 35 pounds per square inch.

A shielded 2-wire line consists of two parallel conductors separated from each other by an insulating dielectric material and encased in a copper-braid tubing which acts as a shield. The assembly is covered with a rubber or flexible jacket to protect the line against moisture and abrasion. Such a line has the advantage of being balanced to ground, since the capacitance between each conductor and ground is uniform throughout its entire length. The shield prevents pick-up of stray fields.

Open 2-wire lines are readily constructed to have impedances of 300 to 800 ohms. Lower impedances require closer spacing of the conductors, hence are desirable only for low power transmission and for reception. Rigid and flexible concentric or coaxial lines are available in impedances as low as 35 ohms.

In the case of open lines, or coaxial lines where the outer shield is one of the conductors, a certain amount of capacitance exists between one side of the line and any obstructions near it; consequently, the current flow is greater in one conductor than in the other. If radiation from the line is to be prevented, the current flow in each conductor must be equal in amplitude, thereby permitting complete cancellation of the magnetic fields which must be equal and opposite in polarity. The shielded line prevents such radiation losses to a considerable degree by maintaining balanced capacitance to ground. However, by using a quarter-wave section as a transformer, connected as shown in Figure 17–24, the unbalance can be transformed into a balanced feed line which may be connected to the center of a doublet. The transformer section of the same material as the coaxial feed line has its inner conductor connected to the outer conductor at each end and spaced ½ to 1 inch from the main feed line. The formula for cutting the quarter-wave section should use 0.95 as the propagation constant since the effective elements of the transformer are the outer braids on the two coaxial cables. If the two parallel sections are strapped together the propagation constant will be somewhat less than 0.95 since the insulation of the cable is the major dielectric of the two sections. The device, nicknamed "Bazooka," when properly designed and installed prevents radi-

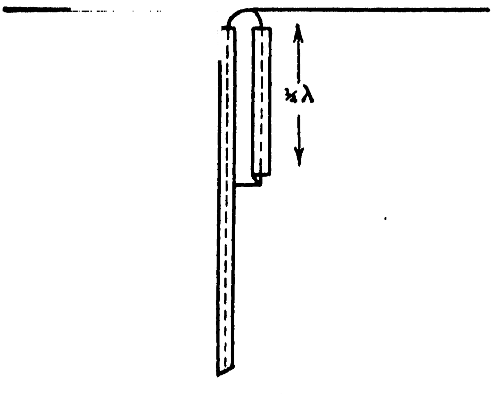

Fig. 17-24. Method of transforming from concentric (unbalanced) line to balanced load (dipole).

ation from the line, thereby insuring preservation of the antenna pattern.

Twisted-pair lines are not used at frequencies much greater than 14 mc because of the high losses occurring in the rubber insulation. In fact, the high losses limit the length of such lines even at lower frequencies.

In the microwave range the transmission line may be simply a tube or pipe. Such a transmission line is called a wave guide. The wave guide differs from the concentric or coaxial line in its mode, or rather modes, of operation. Figure 17-25 shows a section of a wave guide. One might be led to believe that since the two walls are connected electrically, being of the same piece of metal, a short circuit would result. However, this is not so, since, in the wave guide, transmission is due to the electromagnetic field within the pipe. Many types of field patterns are possible. The subject is too complex for a general text. Both rectangular and round wave guides are used extensively. The rectangular guide has in general less losses than the round guide.

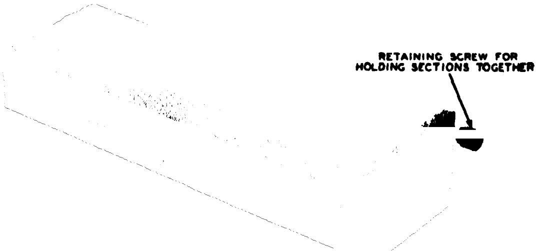

Fig. 17-25. Section of a waveguide. (Courtesy Bell Telephone Laboratories.)

17-23. Tuned Open-wire Lines—The "zepplin" feed system, extensively employed by amateurs operating on frequencies above 3500 kc, is a good example of a resonant open-wire feeder system. In this case the voltage and current are *not* uniform along the line as in a line with a source and a load whose impedance matched the line. "Zepp" feeders are employed to energize a half-wave or multiwave doublet system at a point of maximum voltage.

The feeder is essentially a full-wave doublet folded back on itself so that radiation from the two halves partially cancel each other. Since it is necessary to insert an inductance at the center of the doublet, in the form of a turn or two of wire so as to take power from the tank circuit, it is necessary to insert a variable condenser in each leg of the feeders in order to resonate the circuit to the operating frequency. It is essential that each leg be approximately an odd quarter of a wave length long. The system has the advantage of permitting flexibility in frequency of operation. The current distribution along the resonant feeder system is shown in Figure 17-26a. Since the currents in the two wires of the transmission line are in phase opposition, radiation from the line is reduced. It is by no means negligible.

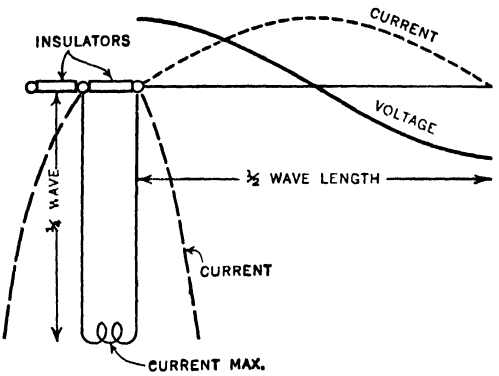

Fig. 17-26a. Resonant line and voltage-fed dipole.

17-23a. The Tunable Doublet—Figure 17-26b shows a current-feed as contrasted with the voltage-fed system just described. It *becomes* a voltage-fed system, however, when the antenna is operated on even harmonics of the fundamental frequency. When operated on a harmonic frequency there will be multiple lobes of radiation but the minor lobes

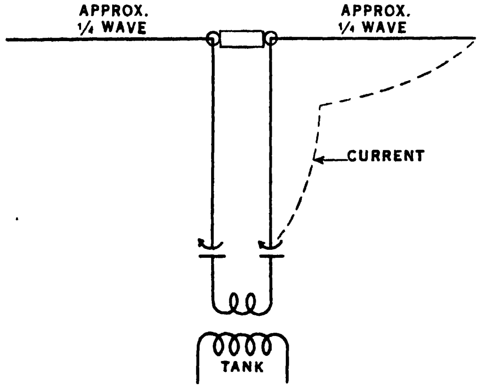

Fig. 17-26b. Resonant line and current-fed dipole.

are quite small as compared to the major lobes. The antenna need not be exactly an electrical half-wave in length as long as the whole system is resonant *as a unit*. Only one tuning condenser need be used if it is connected at the center of the coupling coil. Since one of the current maxima is located at this point a large capacitance may be necessary. Therefore, the single condenser is frequently replaced by two condensers, mechanically coupled but electrically insulated from each other, each being in series with a line wire.

Certain feeder lengths will require that the condenser be placed across the coil rather than in series with it.

17-24. Nonresonant Feeders—There are several methods of feeding power to an antenna by means of untuned or nonresonant transmission lines which include the various types of coaxial cable (concentric), twisted pair, shielded pair and two-wide (twin-lead) or parallel conductor line. Figure 17-27 shows a half-wave antenna current fed at the center with twisted pair feeders. Serious losses appear in the line unless the line is chosen to have an impedance matching that of the dipole center, i.e., about 72 ohms. Line impedance is discussed in the next section. A line of higher impedance may be matched to a dipole by use of the scheme of Figure 17-28.

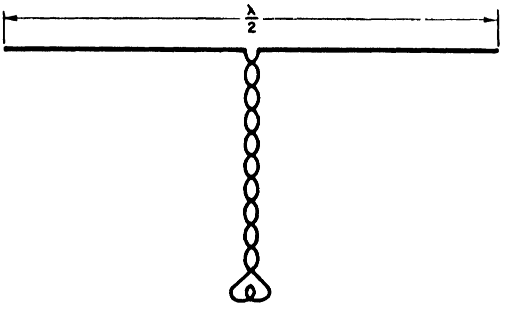

Fig. 17-27. Half-wave dipole fed with twisted pair.

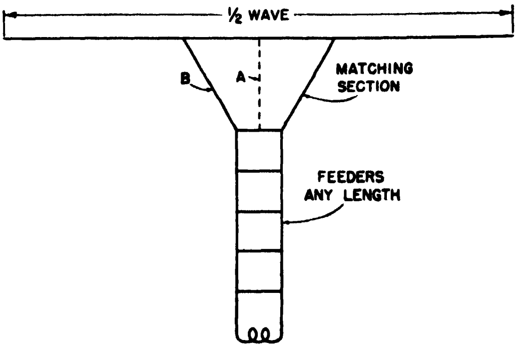

Fig. 17-28. Delta-match antenna. Example of feed system intermediate between current-feed and voltage-feed.

17-25. Characteristic or Surge Impedance—All transmission lines possess distributed inductance, capacitance, and resistance. The inductance is in series with the line, the capacitance across the line, and resistance consists of wire resistance, also leakage paths across the line plus dielectric and radiation losses. In radio circuits using coils and condensers the inductance and capacitance are present in definite lumps but in r-f transmission lines they are, as previously stated, distributed and cannot be separated from each other. The value of these properties determines the characteristic impedance of the transmission line. The resistance is usually neglected and the surge or characteristic impedance defined in terms of the size and spacing of the conductors and, in some cases, the dielectric separating them.

The characteristic impedance of an open two-wire line with air as a dielectric may be obtained from the formula:

$$Z_0 = 276 \log_{10} \frac{b}{a}$$

where *b* is the spacing between the centers of the conductors and *a* the radius of the conductors. Both *b* and *a* may be stated in any units, but the same unit must be used for both.

Because the difference in construction of a concentric line causes the distributed inductance and capacitance to vary in manner different from the open two-wire line the characteristic impedance of the concentric line is:

$$Z_0 = 138 \log_{10} \frac{b}{a}$$

where *b* is the *inner* diameter of the *outer* conductor and *a* is the *outer* diameter of the *inner* conductor.

When the transmission line is terminated in its characteristic impedance, the maximum power is delivered to the load. The voltage and current along the line do not pass through nodes and loops, i.e., there are no standing waves. If the termination is not correct, reflection of energy occurs and standing waves are formed on the line and, instead of the load taking the energy from the line as fast as it is delivered, some is dissipated in the line. A transmission line is said to be "flat" when it is free of standing waves.

The presence of reflected or standing waves can be determined by running a current-indicating device along the line and noting the presence of current loops and current nodes or by the use of other devices described later in this chapter. In the case of a coaxial line constructed of a solid or continuous insulating material, standing waves sometimes manifest themselves by heat which can be felt at half-wave lengths along the line. The losses in coaxial lines, especially those having rubber dielectric, increase rapidly with the increase in ratio of standing waves since the losses in solid dielectric increase as the square of the voltage, or more.

Standing waves on a transmission line upset the desired radiation pattern of an antenna since the line itself is then acting as part of the radiating system and new lobes of radiation appear, some of which may cancel as well as reinforce the main lobes by the antenna.

17-25a. Propagation Constant—In Chapter I it was stated that the velocity of radio waves in free space is equal to the velocity of light, or approximately 300,000,000 meters per second. Because radio-frequency energy travels (or is propagated) more slowly through a wire than in free space, a wave length is shorter on the wire than in space. The reduction in velocity results from the capacitance effects between the wires themselves and between each wire and ground as well as the increase in effective capacitance occasioned by the presence of the insulating material between the wires. The factor by which the velocity in a line is reduced from the velocity in free space is called *the propagation constant.* The propagation constant for some common lines is as follows:

Parallel line (air insulated)	0.975
Parallel tubing (air insulated)	0.95
Parallel line (polyethylene insulated 300 ohm line)	0.82
Coaxial line (air insulated)	0.85
Coaxial line (RG-58/U)	0.66
Coaxial line (RG-11/U)	0.66
Twisted pair	0.60

It is necessary to take into consideration the propagation constant when designing transmission lines of specific wave lengths or fractional wave lengths and antennas having spaced elements.

17-25b. Effects of Weather—Certain flat twin-lead types of transmission lines employ a continuous web of polyethylene as the insulation between the conductors and since the capacitance between the conductors is a function of the characteristic impedance anything that changes the dielectric constant of the capacitance formed by the two wires will necessarily change the impedance of the line and hence may result in a mismatch. In the case of the 300-ohm type of twin-conductor transmission line, the wires are so widely separated that the fields set up about the conductors operate in the immediately surrounding air as well as the polyethylene insulation. Under dry conditions the value of C is dependent only on the air and insulator. However, when the lines become wet, a third element is introduced, producing a new value of C and consequently a change in the characteristic impedance. The effects of surface moisture are less noticeable with the more closely spaced polyethylene transmission lines. Some types of twisted-pair lines become almost useless during rain.

17-26. "Delta-match" Impedance—Figure 17-28 shows the "delta-match" system of terminating a high-impedance transmission line at a half-wave doublet. The impedance match is approximated by fanning out the transmission line in the form shown. The constants A and B of the delta match arrangement are rather critical and the antenna must be resonant at the operating frequency in order to minimize standing waves on the line. If the antenna is to be operated on one of its harmonics, the dimensions A and B of the delta portion are different.

17-27. Open Quarter-wave Stub as Impedance Matching Transformer—An open or nonshorted quarter-wave section of transmission line can be used to advantage to couple a two-wire transmission line, without tapping to an antenna; or to couple two transmission lines having different impedance characteristics.

The characteristic impedance of the section required to perform this operation can be obtained from

$$Z_0 = \sqrt{Z_1 \times Z_2}$$

Hence if it is desired to match a 600-ohm line to the center of a half-wave doublet which has a characteristic impedance of 72 ohms, a section would be required to have an impedance of 208 ohms. In practice this is accomplished by using tubing with close spacing, the design being dependent on the inner and outer diameter of the tubing and the spacing.

Half-wave sections may also be used as a matching transformer but do not permit of the flexibility of operation of the quarter-wave section since the section acts as a 1 to 1 transformer and repeats at one set of terminals whatever impedance is present at the other. If the three impedances, i.e., the two lines and the section are of the same general order of magnitude a fair match can be obtained.

17-28. Length of Quarter-wave Sections—The length of a quarter-wave section is as follows:

$$L = \frac{246V}{f}$$

where L equals length in feet, f the frequency in megacycles and V the velocity factor (see table, page 722).

17-29. Impedance Matching Network or Stub—Figure 17-29 shows three arrangements whereby an antenna may be either voltage or current fed by utilizing both a resonant and nonresonant transmission line. The resonant line acts as an impedance transformer. Assume that it is desired to end-feed a half-wave antenna by means of an open-wire 600-ohm nonresonant transmission line. To do this the feeding must be done at a point of maximum voltage. From our previous description of voltage and current distribution we learn that the voltage is maximum at the end of the half-wave antenna and, consequently, presents an impedance much greater than 600 ohms. We have also learned that if a transmission line is to be "flat," i.e., free of standing waves, it must be terminated in its characteristic impedance and the terminating impedance should be approximately a pure resistance. The impedance of a shorted quarter-wave resonant section or stub of a transmission line is zero at the shorting bar, increasing as the open end is approached. Consequently, it becomes a practicable matter to connect a quarter-wave matching stub at the end of a half-wave antenna and properly terminate the 600-ohm nonresonant line. Referring to Figure 17-29a, in order to adjust the section so that the point of connection of the nonresonant line can be made equal to the characteristic impedance of the nonresonant line, it is necessary only to increase or decrease the distance between the shorting bar and the point at which the nonresonant line is to be connected to the stub. As stated previously the impedance is increased as we move outward from the shorting bar. The quarter-wave stub is made resonant at the operating frequency by proper placement of the shorting bar and when this is done maximum voltage appears at the end of the stub where it is connected to the antenna, and when the non-resonant line is terminated in its characteristic impedance at the proper point on the matching stub, maximum transfer of power from the transmitter to the antenna will occur.

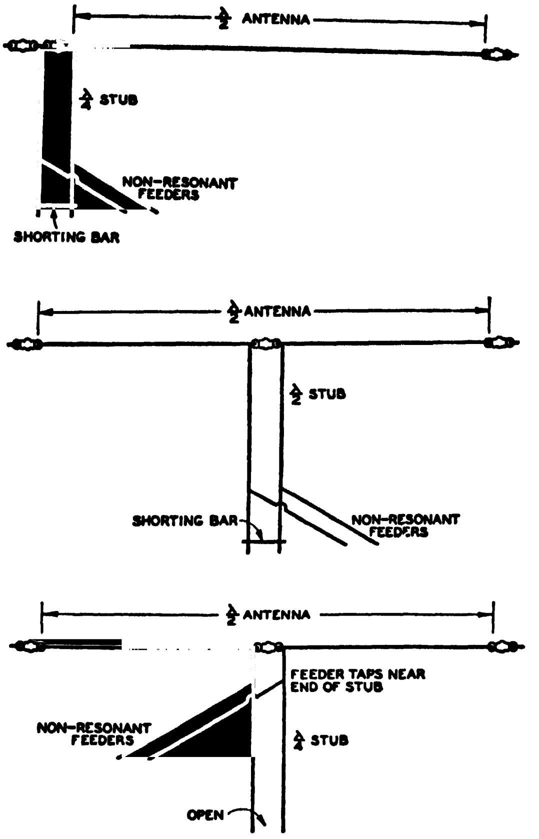

FIG. 17-29. Matching stubs.

17-30. Current Feed with Matching Stub—When a stub is used to current-feed an antenna the case is different in one way only. If a shorting bar is used the stub must be a half-wave (or any number of half-waves) long as in Figure 17-29b. If no bar is used the stub must be ¼ wave long as in Figure 17-29c. In general, shorted stubs are employed in antenna transmission line applications since they have lower radiation losses and are easier to adjust and support.

17-31. Terminating the Shorting Bar—The proper points on the quarter wave at which the shorting bar is to be connected is found by exciting the antenna by coupling another half-wave section close enough to permit detecting points of maximum current when the auxiliary or exciting antenna is energized by a transmitter or signal generator. With the antenna in such a position that the stub can be reached and with the nonresonant feeders disconnected, an r-f milliammeter or low-current dial light should be connected across the stub near the point where it is anticipated the final connections of the stub will be made (near the end) and then moved along the line until the point of maximum current is found. After finding the point of maximum current, remove the current indicating device and solder a wire across the stub at that point.

When an r-f current-squared galvanometer is used the coupling can be made very loose and the power of the transmitter reduced. If a low-current dial light is used sufficient power and coupling should be used to make the light incandescent as it is moved along on the stub. Care should be taken not to burn out either meter or lamp as a point of maximum current is approached.

Precaution should be taken to insure that the d-c plate voltage is not connected to the exciting doublet preliminary to engaging in this tuning procedure since direct contact with the plate voltage might be fatal.

After the shorting bar is properly connected in the case of a quarter-wave stub, the auxiliary antenna is disconnected from the transmitter and the nonresonant feeders connected to the transmitter for operation. The feeders are temporarily connected at a point on the stub about a quarter of a quarter wave from the shorting bar with the transmitter turned on, the feeders are moved up and down until a point is reached where the standing waves are at a minimum.

17-32. Tuning an Open-ended Stub—The process of tuning an open-ended stub is a little more involved than tuning a quarter-wave stub with a shorting bar since it requires a field strength indicating device and pruning of the stub to the proper length. The stub is, for convenience, made slightly longer than the calculated value.

The field strength indicating device can be assembled with an r-f milliammeter and pick-up coil or a tuned circuit operating into a diode rectifier in series with a d-c milliammeter. The field strength meter should be placed sufficiently close to the radiator to get a convenient deflection and as far from the exciting antenna as possible.

With the nonresonant feeders disconnected, the wires of the stub should be either folded back on themselves or clipped a few inches at a time until a peak reading is registered on the field strength current indicating device.

The feeders may then be attached at a distance approximating three-quarters of quarter wave from the end of the stub after which they may be moved along the stub until the standing wave ratio is at a minimum. After the feeders are attached finally the stub may require touching up for a final adjustment to minimize standing waves since the feeders may detune the stub slightly.

17–33. Detection of Standing Waves—The standing wave ratio can be determined:

$$\text{Standing wave ratio} = \frac{E_{\max}}{E_{\min}}$$

The points of maximum voltage on a transmission line can be determined by an r-f voltage indicator or by determining the points of maximum current.

The minimum or nodal points of voltage will occur at points of maximum current, consequently, a voltage maximum will appear at a quarter wave length from the point of maximum current. A standing wave detector operating as a current indicator can be made up with a one-turn pick-up loop of sufficient diameter to fit over the transmission line with the ends connected to a small 6-volt dial light or an r-f thermo galvanometer. A low-range d-c milliammeter connected in series with a crystal detector may also be used as a current-indicating device.

Approximate points of maximum voltage may be detected with a neon bulb but it is essential to keep in mind that once the gas is broken down entirely very little difference in brilliancy can be noted. Furthermore, it is important to be sure that the enamel may not be evenly distributed and deceptive maximum may be detected, should the line have this kind of insulation.

In practice it is possible to obtain at least a 2 to 1 standing wave ratio. An impedance mismatch of several percent is of little consequence as far as power transfer to the antenna is concerned; however, it is important to have the current in each side of the line equal in phase and amplitude. If the currents are not at the same value at points on the adjacent wires of transmission line, radiation losses along the line will be high. This balance can be achieved only by perfect symmetry along the line and with respect to the ground.

17–34. Quarter-wave Stubs as Wave Traps or Filters—Figure 17–30 shows the application of a closed quarter-wave stub as a line filter or wave trap for the purpose of suppressing even harmonic radiation from a transmitter. The closed or shorted quarter-wave stub or filter offers infinite impedance at the resonant frequency but at the second harmonic or any other even order of harmonics the stub offers a low impedance and thus any energy at these frequencies appearing in the line is effectively by-passed to ground. The stub may be connected at any point along the line.

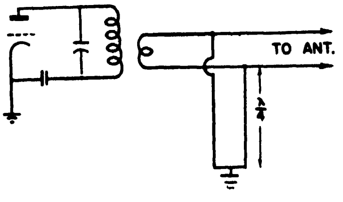

FIG. 17–30. Quarter-wave stub as a filter.

Since the quarter-wave stub offers maximum impedance at the resonant frequency, it may also be used as a metallic insulator to support the transmission line. The shorted end of the stub can be connected to ground thus providing protection from lightning.

An open quarter-wave stub may be used also as a suppressor of even harmonics. In this application the stub is connected in series with the line as shown in Figure 17–31.

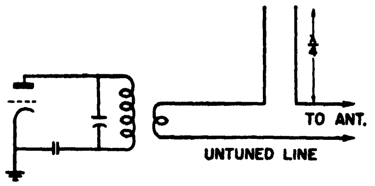

FIG. 17–31. Open quarter-wave stub used as a suppressor of even harmonics.

Neither closed nor open quarter-wave stubs can be used as filters or as a suppressor of odd harmonics since at each odd harmonic frequency the stub is an odd multiple of a quarter-wave and hence offers little impedance at these frequencies.

A quarter-wave stub may be utilized to advantage as a wave trap to eliminate interference to reception. In this case interference from the strong field of an F–M station can be attenuated or eliminated from a television receiver or vice versa by connecting an open-end quarter-wave stub at the terminals of the receiver. The flat or ribbon type 300-ohm line can be used to advantage for this purpose. The stub can be tuned by providing a trombone tuner arrangement in the form of a short length of tinfoil, about 4 inches, as a slider, thereby permitting the use of the stub on several channels according to the frequency of the interference ex-

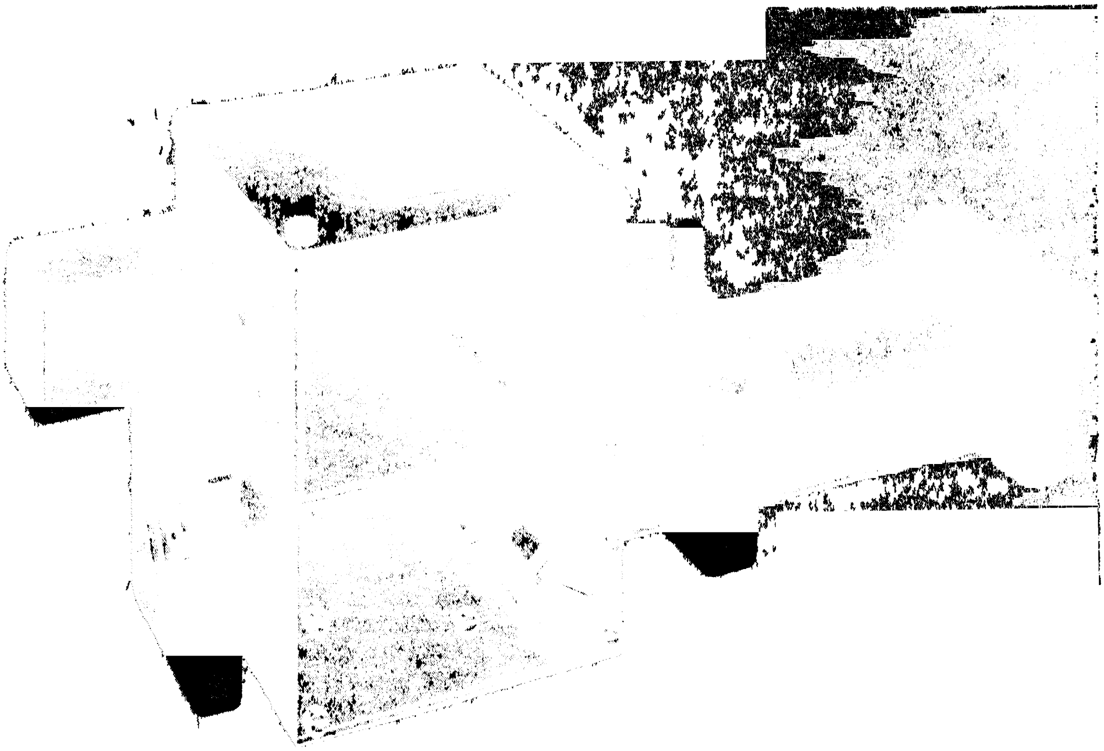

Fig 17–32 Western Electric 3A power and impedance monitor

perienced at the time It will also permit frequency adjustments occasioned by changes in weather conditions

17–35 Monitoring Power and Impedance at High Frequencies—The Western Electric 3A power and impedance monitor shown in Figure 17–32 is a device designed for F–M broadcasters by the Bell Telephone Laboratories to serve as a radio-frequency wattmeter to make standing wave ratio measurements available at all times, and to protect the transmitter and transmission line from damage due to radical changes in transmission line load impedance The 3A monitor is standard equipment in Western Electric 3-kw, 10-kw and 50-kw F–M transmitters

The method employed in this device was first disclosed by J F Morrison of the Bell Telephone Laboratories in a paper before the I R E Convention in March 1947[5]

The function and features of the device have been described by E L Younker as follows[6]

> "The power delivered by the transmitter may be readily determined by means of the power and impedance monitor even though the input impedance of the antenna is not known An actual power determination consists simply of taking two readings of a specially calibrated power output meter installed on the transmitter front panel, and subtracting the smaller reading from the larger The larger power reading is equal to the amount of power incident upon the antenna system (that power which would be absorbed by the system if the antenna impedance matched the line impedance perfectly), while the smaller is equal to the amount of power reflected back to the transmitter by the antenna (such reflection will occur if the antenna impedance does not match the transmission line) The power output meter normally indicates the incident power by merely depressing a switch, the same meter is made to indicate reflected power
>
> "Thus the power monitor gives an accurate indication of the r-f power actually delivered to the transmission line and antenna system, regardless of the magnitude of the transmission line standing wave ratio The commonly used single probe voltmeter or ammeter method has a large inherent uncertainty in the presence of a standing wave of unknown phase and magnitude The possible error in power determination as a function of standing wave ratio (SWR) is shown by curve A and B in Figure 17–33 For example, if the standing wave ratio is two, the computed power will be twice the true power if the probe is at a maximum position, while the computed power will be one-half the true power if the probe is at a minimum position If the probe does not fall at a maximum or minimum point, the error will lie on the vertical line between curves A and B which intersects the abscissa at SWR = 2 Since the position of a standing wave is seldom known, a serious uncertainty, if not actual error, nearly always exists On the other hand, since the indication of the power monitor has been made insensitive to the phase of the stand-

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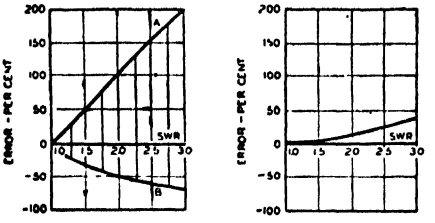
[5] 'A Method of Determining and Monitoring Power and Impedance at High Frequencies " J F Morrison and E L Younker

[6] An RF Wattmeter and Impedance Monitor for FM Broadcasting," E L Younker, Western Electric *Oscillator*, July 1947

ing wave by taking both the current and the voltage samples at the same point in the line, the error in power determination with the monitor is very small, regardless of the standing wave ratio. Experimental measurements have shown that the measured power agrees with the true power to within 5 per cent for standing wave ratios up to 2.5 and to within 10 per cent for standing wave ratios from 2.5 to 6.



A.
CURRENT
OR
VOLTAGE MONITOR

B.
COMBINED CURRENT
AND
VOLTAGE MONITOR

FIG. 17–33. Possible error in power determination as a function of standing wave ratio.

"Measurement of a transmission line impedance mismatch is equally simple with the monitor. The reflected power reading of the power output meter is in itself a measure of the line mismatch; this reading will be zero for a perfectly matched line and should not exceed about 5 percent of the incident power for a reasonably well-matched line. The incident and reflected powers are intimately related to the standing wave existing on the transmission line and therefore the two meter readings mentioned above provide sufficient information for the determination of the standing wave ratio. The standing wave ratio is in practice determined by reference to a table or chart which relates standing wave ratio to incident and reflected power. The power monitor's advantages of simplicity and speed are apparent when one recalls the labor of making standing wave measurements with the 'slotted-line section,' where a voltage or current probe must be moved along the transmission line for at least a quarter wavelength (approximately 2½ feet at 100 mc).

"A circuit is incorporated in the monitor which protects the transmitter against the harmful effects of large changes in the load impedance. It also protects the transmission line against arcs, initiated by lightning or other causes and sustained by r-f power derived from the transmitter. This protective ability of the Power Monitor is based on the fact that as the transmission line mismatch increases, the amount of reflected power also increases. A small d-c current, which is proportional to the reflected power, flows through the winding of the relay. The sensitivity of the relay is adjusted so that operation will occur whenever the reflected power exceeds a predetermined value. Operation of the relay applies a cut-off bias to two frequency doubler stages in the transmitter, thus interrupting the r-f output of the transmitter. With no r-f output from the transmitter there is no reflected power, and if the trouble is cleared, normal operation is restored. The duration of the off time is ⅒ second. A small signal light, which continues to glow until reset by the operator, indicates that the interruption was caused by a high power reflection on the line.

"Figure 17-34 shows how voltage and current pickups are used in the power monitor. Two circuits (one to measure incident power, the other to measure reflected power) are arranged back to back on a coaxial line inside a shielded enclosure. These circuits are alike except that in the incident power circuit the fixed resistor is connected to the load side of the slot while in the reflected power circuit the resistor is connected to the generator side of the slot. Each circuit is an independent unit; they are placed near each other only for mechanical convenience in the circuit which measures incident power, an r-f voltage due to the voltage and current pickups is impressed upon a crystal rectifier. The rectified current from the crystal flows through potentiometer POT. 3 and a d-c milliammeter. Switches S1 and S2 are normally in position 1. Switch S1 is used only during calibration of the power monitor; Switch S2 is used during operation of the transmitter to connect the power output meter to either the incident or the reflected power circuit. In the circuit which measures reflected power, a voltage due to the other set of voltage and current pickups is impressed upon a crystal rectifier. The rectified current from this crystal flows through the winding of a sensitive relay and the potentiometer POT. 2 to ground. This rectified current may be made to flow through the milliammeter by throwing Switch S2 to position 2. It should be noted here that a rectified current proportional to the amount of power reflected by the antenna flows through the relay winding regardless of whether or not the reflected power is being indicated on the meter. Thus the protective relay is operative at all times.

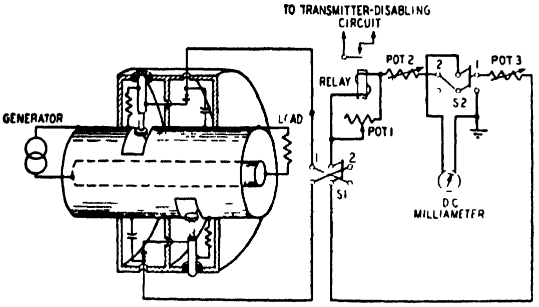


FIG. 17–34. Western Electric 3-A power and impedance monitor.

"The voltage pickups in the r-f circuits are made variable to permit the adjustment of the magnitude of the line voltage sample relative to the line current sample. When these voltage samples which are impressed upon the crystal rectifiers are properly proportioned, the output of the incident power crystal is independent of any energy reflected by the antenna, and the output of the reflected power crystal is independent of energy incident upon the antenna. The balance adjustment of the voltage pickup is independent of frequency; for this reason one factory adjustment of the voltage pickup is all that is required, no matter at what frequency in the FM band the Power Monitor is used.

"The monitor is calibrated as a wattmeter by determining the amount of power dissipated in a matched load, and then adjusting the potentiometer in the d-c circuit (Figure 17-34) to obtain the correct indication on the power output meter. The power output meter is a d-c milliammeter mounted on the transmitter front panel for the convenience of the operator, which has been calibrated in kilowatts according to the experimentally determined relation between r-f power and rectified current of the germanium crystal rectifiers used in the monitor. The kind of scale obtained from this calibration is illustrated in Figure 17-35 where the power output meter for a 10 kw transmitter is shown. The fact that the scale is expanded in the lower power region is significant because good accuracy is desired in the measurement of low (reflected) as well as high (incident) powers."

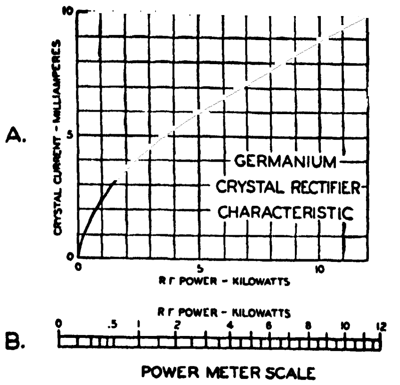


Fig. 17–35.

An example of a test setup for a transmitter is shown in Figure 17–36.

17-36. Long Wire Antennas—It has been stated that when an antenna is excited at an integral multiple of a half-wave length (harmonic excitation) there results additions and cancellations of current in the half-wave which produce several lobes of radiation at various angles with the antenna.

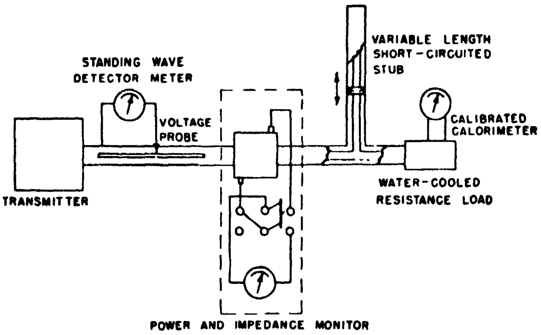

STANDING WAVE DETECTOR METER
VOLTAGE PROBE
TRANSMITTER
VARIABLE LENGTH SHORT-CIRCUITED STUB
CALIBRATED CALORIMETER
WATER-COOLED RESISTANCE LOAD
POWER AND IMPEDANCE MONITOR

Fig. 17–36. Representative test circuit.

The current in each half-wave section is out of phase and to maintain this out of phase condition throughout the length of the antenna, it is necessary to feed it at one end as voltage feed or in the center of a half-wave at a current loop. When the antenna is more than four half-wave lengths long the end lobes of radiation increase while the broadside lobes become smaller although numerous in number as the order of harmonic operation is increased.

The directivity of a long line antenna does not increase much as the length of the radiation is increased beyond 15 wave lengths. In fact, at about 15 wave lengths the antenna becomes aperiodic and will radiate well over a wide range of frequencies.

In the case of a long wire antenna operating at several half-wave lengths it is necessary to use a different formula than that used for a simple half-wave doublet, since the end effects are present only on the end sections. In the remaining portion of the antenna length, these effects are absent and the antenna length is approximately that of an equivalent portion in free space. Hence the length of a long wire antenna is calculated from the formula:

$$L = \frac{492(n - 0.05)}{f}$$

where L is length in feet, f the frequency in megacycles, and n the number of half waves on the antenna.

17-37. The V Antenna—One of the simplest types of long wire directive antennas is the V shown in Figure 17-37, which consists of two long resonant wires such that each wire carries equal current and have the same phase relation. A single V antenna is bidirectional in a direction opposite the apex of the V. The amount of directivity obtainable is greater the longer the wires and in some commercial applications each leg may be at least 8 wave lengths long and with such an array a power gain of 39 is obtainable. A lesser degree of directivity results from reduction in the number of wave lengths per leg. When the sides of the V are short the apex angle at which the power gain of the antenna is maximum is small. For example, if the legs are one wave length long, maximum gain is obtained with an apex angle of 90° rather than the 105° corresponding to exact superposition of the major lobes.

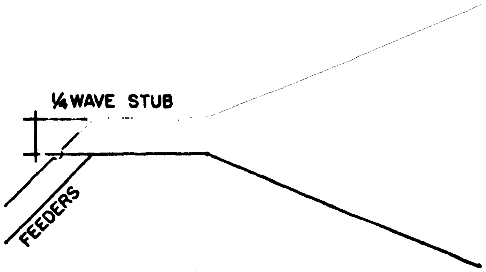


Fig. 17–37. V antenna.

V antennas can be stacked or displaced horizontally for the purpose of achieving both directivity and gain. The antenna may be fed by terminating it in its characteristic impedance, by proper choice of transmission line, or by use of a matching transformer.

17-38. Rhombic Antennas—The rhombic or diamond antenna shown in Figure 17-38 has long

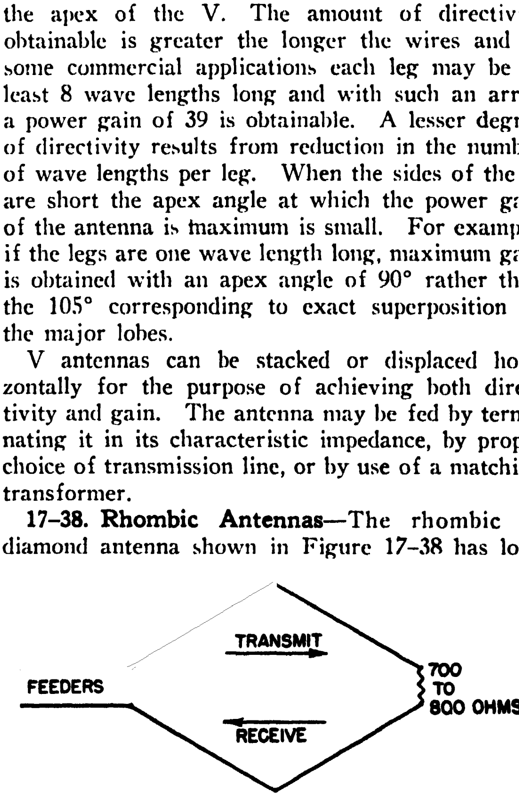


Fig. 17–38. Rhombic antenna.

been popular for both transmission and reception of radio signals. Gains of 13 to 20 db are readily obtained in both transmission and reception. Generally it is erected horizontal to the earth and supported on poles at each corner giving it the configuration of a diamond from whence it derives one of its identifications. The rhombic antenna, if terminated in a resistor as shown, is essentially nonresonant and, therefore, not critical as to frequency. It can be erected vertically and lends itself to very-high-frequency applications where directivity and gain are desired.

In order to realize the gain of which the rhombic antenna is capable each leg of the antenna should be at least three times the wave length. As the length of each leg is increased the gain is increased and the beam narrowed. If the length of a leg is six or more times the wave length, the beam becomes so narrow that the angle of orientation in the direction of transmission must be quite accurate. A power gain of 8 to 1 can be secured with such an antenna having six wave lengths on each leg. The directivity of the rhombic antenna is dependent on the height above ground, the side angle, and the over-all length of each of the four wires comprising the radiators.

The terminating resistance is approximately 700 to 800 ohms and when properly terminated the forward gain is increased and the radiation is unidirectional, as shown by the arrows. When employed for transmission, the terminating resistance must be capable of dissipating about one-third of the power output of the transmitter. When this resistance is omitted the antenna is bidirectional having about the same gain forward and backward.

The input resistance of the rhombic antenna, as reflected into a transmission line that feeds it, is somewhat smaller than the terminating resistance by 50 to 100 ohms. Consequently, if the terminating resistance is 700 ohms, the transmission line should have a characteristic impedance of approximately 600 ohms.

If it is desired to make the rhombic antenna bidirectional, feeders are run to the far end and by means of switches and relays terminating resistors are cut in or out according to the mode of operation selected.

17-39. Franklin or Colinear Antennas—The Franklin antenna consists of a number of half-wave dipoles placed end to end, all operating in phase. They are coupled together by coils tuned to resonate at the operating frequency. These coils are in effect nonradiating half-wave sections. As the currents in the active, or radiating, sections are all in phase the effect is to radiate a disc-shaped, rather than a doughnut-shaped field, that is, the radiation is decreased at high angles and increased at low angles as shown in Figure 17-39. Low-angle radiation at high frequencies is conducive to long-distance transmission at high frequencies. This is readily understood if one remembers that the angle of incidence from the ionosphere is equal to the angle of reflection. Consequently, an antenna designed to radiate at low angles will have its energy returned to earth from the ionosphere at greater distances than one designed to operate with high angles of radiation.

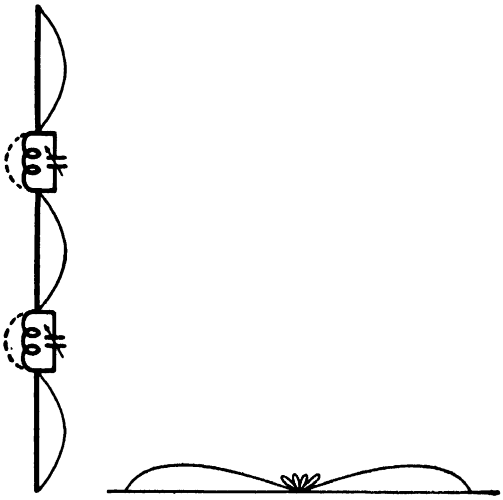


FIG. 17-39. Colinear or Franklin antenna.

17-40. Broadside and End-fire Directivity—Whenever the spacing and phasing of the elements of an array are such that the direction of maximum radiation or reception is broadside to the plane of the wires comprising the antenna, it is referred to as a broadside array. The Sterba or barrage antenna described subsequently is one form of a broadside array. Broadside arrays can be suspended either horizontally or vertically, depending upon the kind of polarization of the radiated wave desired. When the array is suspended horizontally the horizontal pattern is that of one element.

17-41. End-fire Arrays—If the phasing and spacing is such that the direction of maximum radiation occurs along the line of the antenna elements, the array is said to have end-fire directivity. End-fire directivity is accomplished by spacing two half-wave dipoles or colinear elements at various separations in fractions of a wave length, generally less than ½ wave length displacing the currents in the elements by 180°. The gain at ½ wave length spacing is about 2.2 db whereas ⅛ wave length spacing increases the gain to 4.3 db over a single dipole. Proper phasing is accomplished by the manner in which the transmission line is connected to the elements.

17-42. Multiple Stacked Arrays—One of the first types of stacked dipole arrays was developed by E. J. Sterba of the Bell Telephone Laboratories for use on transoceanic radiotelephone circuits and is identified as the Sterba curtain. The original Sterba curtain consisted of several half- and quarter-wave elements stacked vertically so as to radiate a vertically polarized wave. However, merely by turning the antenna on its side, it can be used for horizontal polarization. The array as shown in Figure 17–40 is constructed of one or more half-wave sections in phase with a quarter-wave section at each end. Since the wires of the elements are one continuous length of wire, it is possible to connect them to a source of alternating current of sufficient power to melt ice and snow in the northern latitudes.

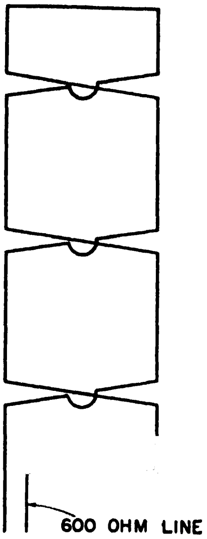


FIG. 17–40. Sterba antenna, vertical polarization, bent dipoles.

The a-c mains can be attached to a quarter-wave stub, thus preventing the r-f energy from backing up into the power lines.

The Sterba curtain with its half-wave length spacing of the elements has a comparative high radiating resistance and, consequently, is easy to feed and has low inherent losses as compared to close-spaced arrays. The Sterba curtain when elevated horizontal to the ground is bidirectional. Figure 17–41 shows various methods of feeding such an array.

There have been several adaptations of the Sterba array employed by amateurs and identified as the "Lazy H" and X–H array as shown in Figure 17–42, the latter an expanded version of the "Lazy H" but instead of one-half wave spacing the two sets of colinear elements are spaced approximately 0.65 of a wave length By using this increased spacing, increased broadside directivity is achieved. The phasing sections are not transposed as in the case of the "Lazy H." The X–H array can be used on half frequency without change thereby permitting two-band operation. In other words, if the array is designed for 28-mc operation, it can be used for 14-mc operation; however, the gain at the half-frequency will be somewhat decreased.

Stacking of horizontal antennas permits attaining increased gain without added horizontal directivity.

17–43. Close-spaced Arrays—Close-spaced arrays are those in which the spacing of the elements is less than ½ wave length. Dr. G. H. Brown of RCA has done considerable research in the field of directive antennas and has shown that it is possible to use spacing as low as 0.05 wave length.

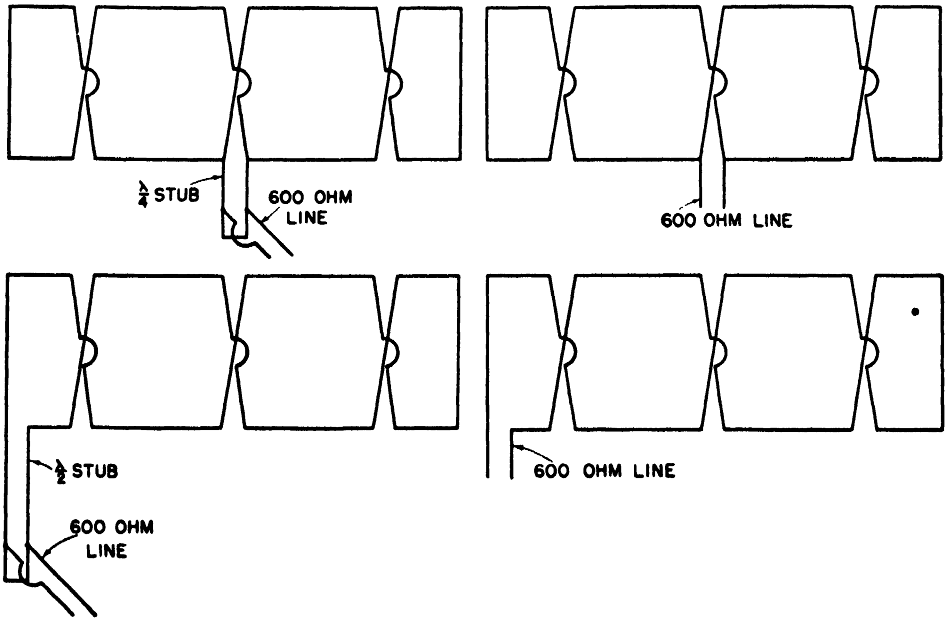


FIG. 17–41. Sterba antenna showing various methods of feeding.

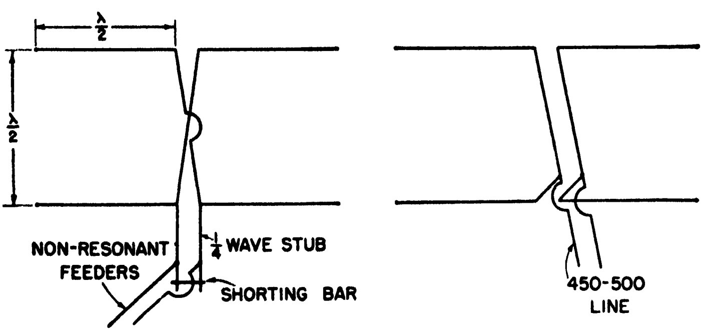


Fig. 17–42. "Lazy-H" and "X-H" arrays.

One of the most popular of the close-spaced arrays employed by amateurs is the Kraus flat top beam-depicted in Figure 17–43. Close spacing of the elements makes it possible to secure the proper phase relation by crossing the wires at points of maximum voltage, instead of resorting to phase reversing half-wave sections as employed in the Franklin antenna. Any number of sections may be used, dependent upon the space available, however, there is not much gain secured when more than four sections are employed.

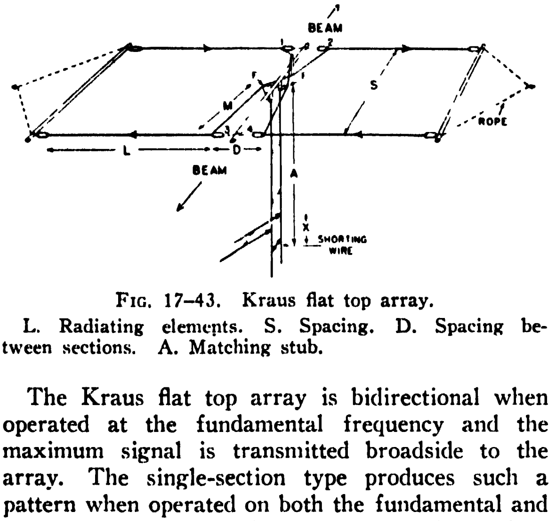


Fig. 17–43. Kraus flat top array.
L. Radiating elements. S. Spacing. D. Spacing between sections. A. Matching stub.

The Kraus flat top array is bidirectional when operated at the fundamental frequency and the maximum signal is transmitted broadside to the array. The single-section type produces such a pattern when operated on both the fundamental and second harmonic. Multisection types have four main lobes of radiation on the second and higher harmonics. The gain over a single dipole is as follows:

1 section: 4 db
2 section: 6 db
3 section: 7 db
4 section: 8 db

It is necessary to use tuned feeders if the flat top beam is to be used on more than a single frequency band. In general, the beam is fed at the center when used as a flat top; however, if suspended vertically it is of advantage to feed it at the lower end.

17–44. Reflectors—The use of reflectors to give unidirectional transmission is as old as Heinrich Hertz's pioneer work. Today a "parasitic reflector" is taken to mean an antenna excited by absorption from the field of the main antenna. It is as a rule equal to or longer than the antenna. The meaning of "energized reflector" is obvious. For instance, in the Kraus flat top, we have such a device.

17–44a. Unidirectional Dipole Arrays—G. H. Brown[7] in his classical paper on directional antennas explained how a unidirectional radiation pattern could be developed by using two antennas having the proper spacing and phase relations, thereby providing a means of securing directivity and gain. Examples are given by Dr. Brown which show how such arrays can be used to protect the service areas of broadcasting stations operating on the same frequency assignments.

In the case of a single parasitic reflector, it was found that spacings less than a quarter-wave length are desirable in both the transmitting and receiving case. Also, Dr. Brown showed that the parasitic antenna functions equally as well as a director or reflector. The spacing and length of the parasitic element determine whether it is used as a reflector or director. A parasitic reflector is always a little longer than an electrical half-wave length and a director a little shorter than an electrical half-wave.

17–45. Four-element Close-spaced Arrays—Both the forward gain and front-to-back ratio are improved as the number of elements are increased from two to four. The following measurements are due to Rex Bassett.[8]

Type	*Gain (db)*	*Front-to-Back (db)*
2 element	4	10
3 element	10	30
4 element	13	35

Type	*Multiplying Power*	*Front-to-Back Power*
2 element	2½ times	10 to 1
3 element	10 times	1000 to 1
4 element	20 times	3100 to 1

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[7] G. H. Brown, "Directional Antenna," *Proc. I.R.E.*, January, 1937.

[8] "The 4-Element Rotary," Rex Bassett, *Radio*, May, 1939.

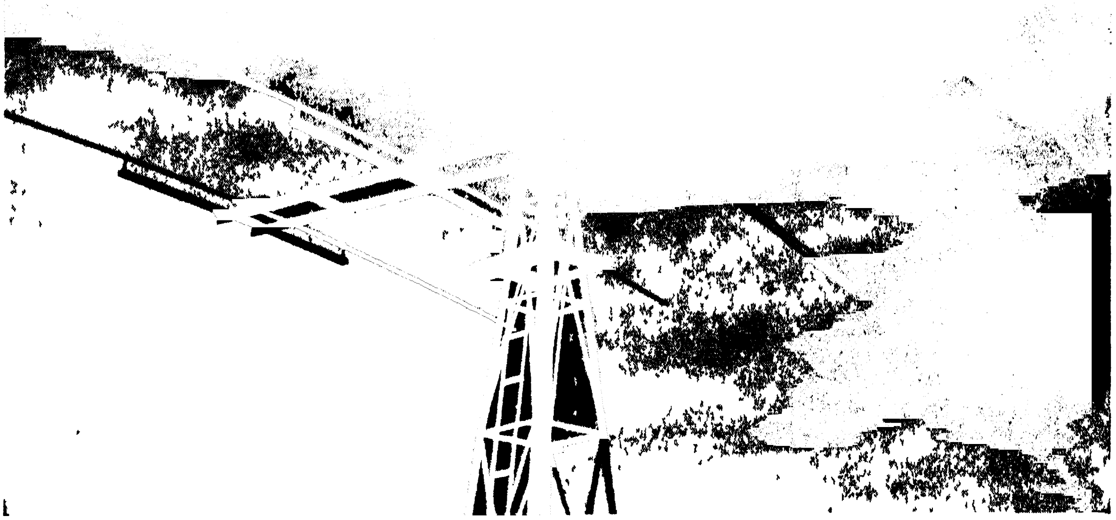

FIG. 17–44 Four-element array.

In the case of a four-element array the elements comprise a radiator, a reflector and two directors of equal length, as shown in Figure 17–44.

The radiation resistance, which represents the impedance at the center of the radiator or driven element, is shown in the following table for each type of array

Type	*Radiation Resistance*
2 element	14 ohms
3 element	8 ohms
4 element	5 ohms

As a result of the low resistance the currents are high and the r-f voltage at the ends of the elements is also high. Good insulation is required The phase relation between the elements will be affected in wet weather if poor insulation is used Close-spaced arrays used by amateurs generally consist of self-supporting quarter-wave elements, thus avoiding insulation difficulties at points of high r-f voltage. Since the Q of a close-spaced array is high, it is selective as to frequency; consequently the efficiency falls rapidly either side of the resonant frequency.

17–46. Power Gain as it Affects the Dipole—When a half-wave dipole is terminated correctly in the transmission line and the latter matched correctly to the receiver input impedance, the voltage on the transmission line is:

$$V_{tl} = \frac{\lambda E}{2\pi} \cdot \sqrt{\frac{Z_c}{R_r}}$$

where Z_c = the characteristic impedance of the transmission line
R_r = the radiation resistance of the half-wave dipole
λ = the wave length in meters
E = the field intensity in millivolts per meter
V_{tl} = voltage on the transmission line, in millivolts

It is assumed that the dipole is cut to the correct length for the operating frequency. Consequently, it can be seen that if the wave length is decreased the voltage on the transmission line and, hence, at the terminals of the receiver will decrease accordingly. If the frequency is multiplied by a factor N, the field intensity E must also be multiplied by the same factor to insure maintaining the voltage constant on the transmission line and at the input of the receiver. Since the field intensity varies with the square foot of the power, the latter must be increased N^2 to offset the effect of the shorter

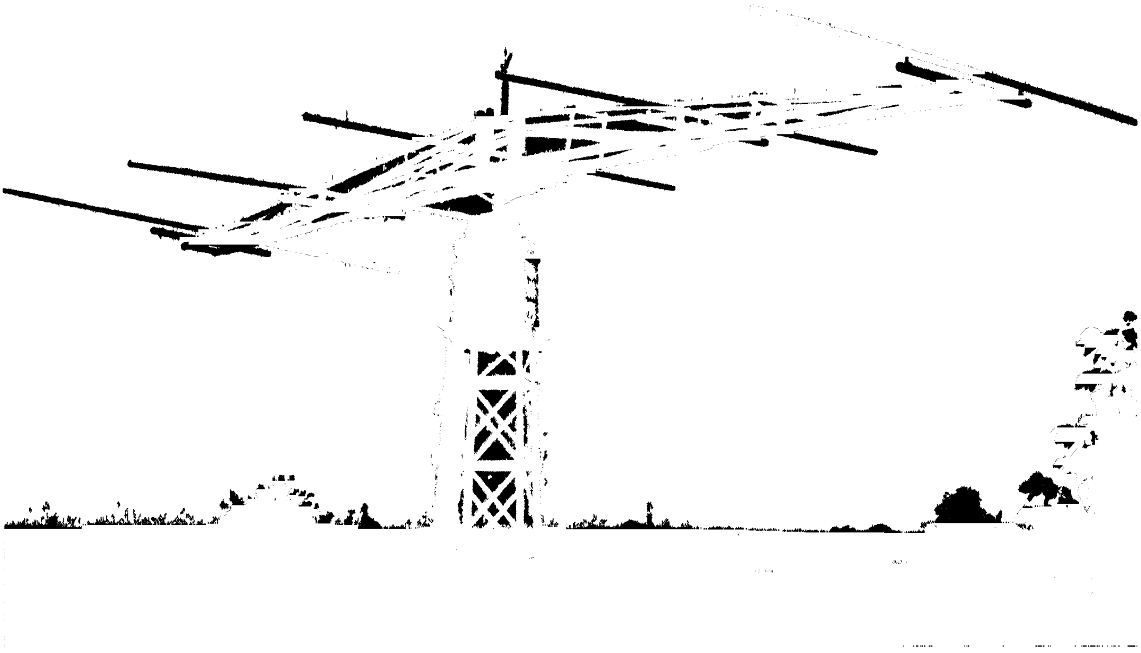

FIG. 17–45. Five-element, quarter-wave spaced, rotary antenna.

dipole at the higher frequency. This is without regard to other factors such as propagation which may act to reduce the voltage on the transmission line as the frequency is increased.

17–47. Power Gain of Antenna Arrays—The maximum possible power gain of a directional antenna in which the effective aperture or mouth opening has a given area (capture area) can be estimated by expressing the area in terms of wave length. The power gain then is 7.65 times the area measured in square wave lengths. The power gain as expressed in terms of the power received by a half-wave dipole at the particular frequency under consideration increases proportionally as the square of the frequency, since for a fixed area the number of square wave lengths included in the area increases in the same manner.

17–48. The Rotary Antenna—Amateurs in particular have found it to be of tremendous advantage in their operations, for the purpose of achieving directivity and gain both in reception and transmission, to use close-spaced arrays so constructed that they can be rotated in the direction of communication. The size of the array elements makes construction and rotation possible from the 14-mc band upward. There are several versions of such arrays. Remote control of rotation from the station can be obtained either electrically or mechanically with provision made from azimuth indication.

17–49. "Quarter-wave" Rotary Array—Figure 17–45 shows a five-element quarter-wave spaced, rotary beam constructed by Donald Whittemore, W2CUZ, with which he conducted tests to compare operation on the amateur ten meter band with closed spaced rotary beams.[9] The elements of this antenna were adjusted to a length in accordance with the standard formula:

Reflector........Theoretical half-wave $\frac{492}{f}$
Radiator.. .. 94% of theoretical half-wave
Director. ..86% of theoretical half-wave

The transmission line was terminated in a simple Y connection and tests showed that the termination is not critical since the Y connectors could be moved several inches each side of the perfect match connection point before the field strength started to decrease.

Field tests developed the following interesting points:

1. Forward power gain measured ten times over the radiator alone.

2. The antenna was not highly critical as to frequency. The transmitter frequency could be shifted from 28.5 to 29.9 mc with negligible change in field strength—an accomplishment impossible with close-spaced arrays.

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[9] Donald Whittemore, "Quarter-Wave Vs. Close-Spaced Beams," *CQ*,, February, 1946.

Figure 17–46 shows the field strength pattern of this quarter-wave spaced, five-element beam. The advantages claimed for this type of array over one with closer spacing are greater ease of feeding, less loss in conductor-heating, and less vulnerability to detuning by rain and ice.

17–50. Television Receiving Arrays—Special problems are encountered with dipoles employed for television reception where the frequencies employed for transmission are in two bands, one extending from 44 to 88 mc (channels 1 to 6) and the other from 174 to 216 mc (channels 7 to 13). For example, a dipole for use on channel 4 would be 73 inches long, whereas channel 10 would be 26 inches long.

One way of achieving broad band response with a single dipole is by feeding a standard 70-ohm dipole with a 300-ohm transmission line. Under these conditions the antenna operates on the principle that the antenna presents a 41-ohm mismatch at resonance resulting in a value of gain less than that of the dipole. As the frequency is varied, the terminal impedance of the antenna rises and at some definite point on either side of resonance, the impedance will be equal to the 300-ohm transmission line. This will result in a better impedance match on each side of resonance and fewer losses due to mismatching, but as the antenna is operated off resonance at these points, the gain is reduced because of detuning and is still less than a standard dipole. These antennas, being high Q circuits, have very sharp frequency response curves, and the useful range covered is not very wide. Because of the gain being under a standard dipole over the entire frequency range it is still not the desired solution to the television receiving antenna problem.

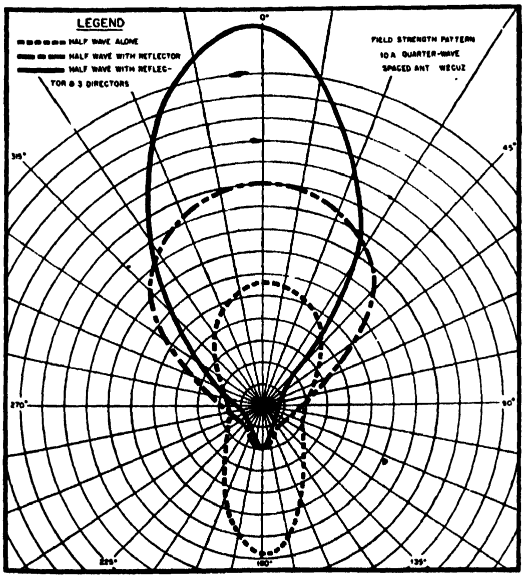

Fig. 17–46. Field strength pattern of antenna shown in Figure 17–45.

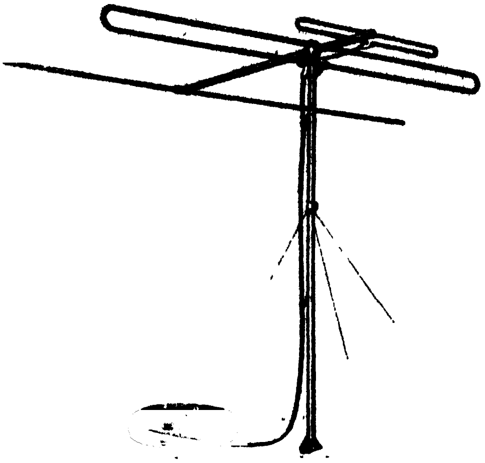

Fig. 17–47. Amphenol television antenna.

Mismatched dipoles are used sometimes with directors and reflectors to provide additional gain. The presence of a director or reflector has a very pronounced effect on the antenna impedance, as has been explained in a previous section of this chapter.

17–51. Two-band Antennas—Figure 17–47 shows the "Amphenol" model 114–005 television array designed for operation on both television bands. Since it was impossible to design a single dipole to operate over such a wide frequency range, it became preferable to use a combination of two antennas of aluminum tubing, one operating over the low-frequency channels and the other covering the high-frequency channels. The low-frequency antenna is a folded dipole with reflector, giving a reasonable impedance match to a 300-ohm line. The spacing between the dipole and reflector was made large to minimize the lowered dipole impedance and make unnecessary the use of frequency sensitive matching transformers. The low-frequency dipole also acts as the reflector for the high-frequency dipole. Figures 17–47a and 17–47b show the radiation pattern of this antenna on both bands while Figures 17–48a and 17–48b show the gain of the antenna over a single dipole.

The low-frequency folded dipole has some pickup on the high-frequency channels and this explains the minor lobes off the sides of the array at the high-frequency end of the upper bands; however, this effect is so small that it is of no consequence.

17–52. VHF and UHF Directive Antennas—As one pushes up into the ultra-high microwave spectrum, new forms of directive antennas come into play. They are used for such applications as radar, marker beacons, landing beams for aircraft, relay controls, and other special applications. Figure 17–49 shows four types of such directive antennas.

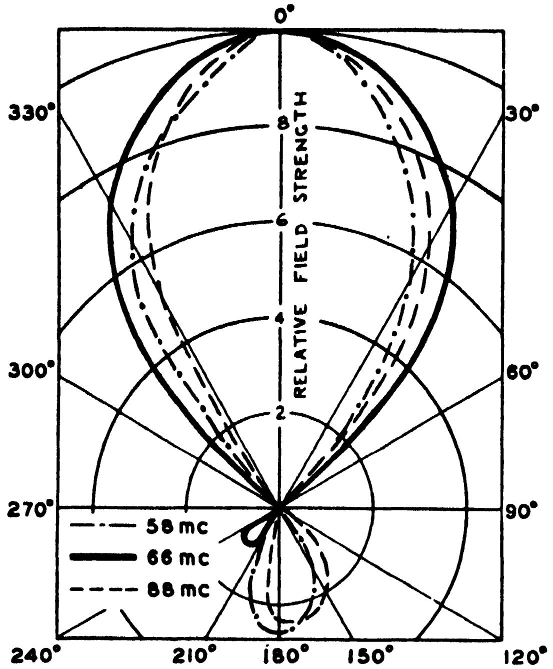

Fig. 17–47a. Radiation pattern of Amphenol model 114-005 antenna.

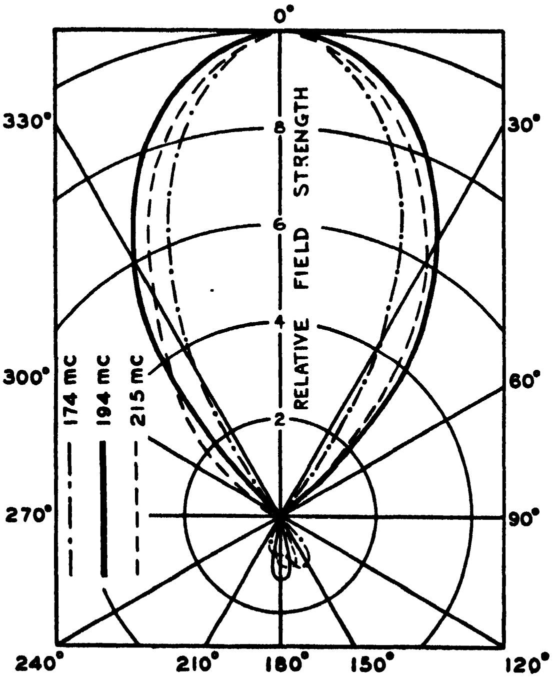

Fig. 17–47b. Radiation pattern of Amphenol model 114-005 antenna.

17–53. Yagi Arrays—The Yagi array shown in Figure 17–49a consists of a driven element, a reflector, and one or more directors. Power from the transmitter is fed to the driven element by a transmission line. The reflector and director elements are parasitically excited from the driven element with such a phase relation with respect to the driven element that the field is reinforced in the forward direction into a narrow beam. Except for the frequency and number of elements, this is the same array as Figure 17–43.

Figure 17–50 shows a series of dipoles employed in a Yagi directive array in connection with an aircraft ground control approach system (GCA). To obtain the peculiarly shaped antenna beam required, an array of 33 probe-fed, half-wave dipoles, mounted in a section of waveguide, is employed. At the extremely high frequencies used, the half-wave antennas are approximately 5 centimeters over-all, and hence the array is only about 7.5 feet long. By placing this array along the focal line of a semi-cylindrical aluminum reflector of parabolic cross section, an azimuth antenna pattern having a beam width of less than 7° between half power points is obtained.

17–54. Parabolic Reflectors—On p. 676 a photograph is shown of two parabolic reflectors employed to transmit and receive 18 centimeter waves across the English Channel with only a power of one-half

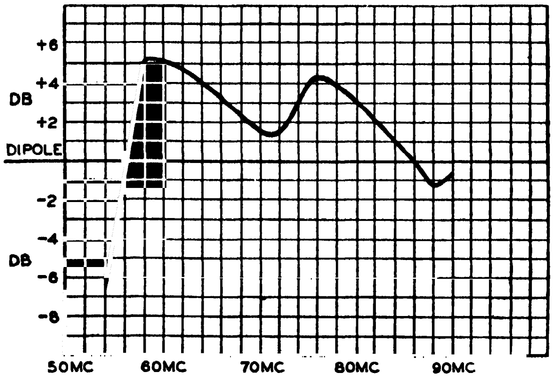

Fig. 17–48a. Gain of Amphenol model 114-005 antenna over a dipole, 54 to 88 mc.

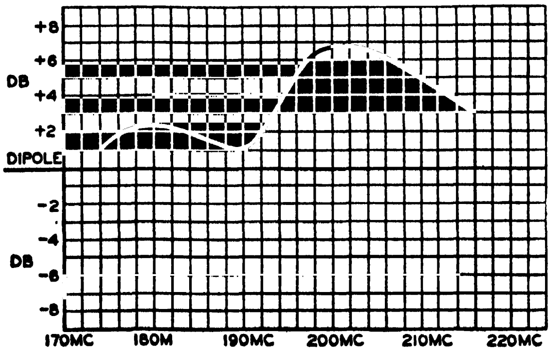

Fig. 17–48b. Gain of Amphenol Model 114-005 antenna over a dipole, 174 to 216 mc.

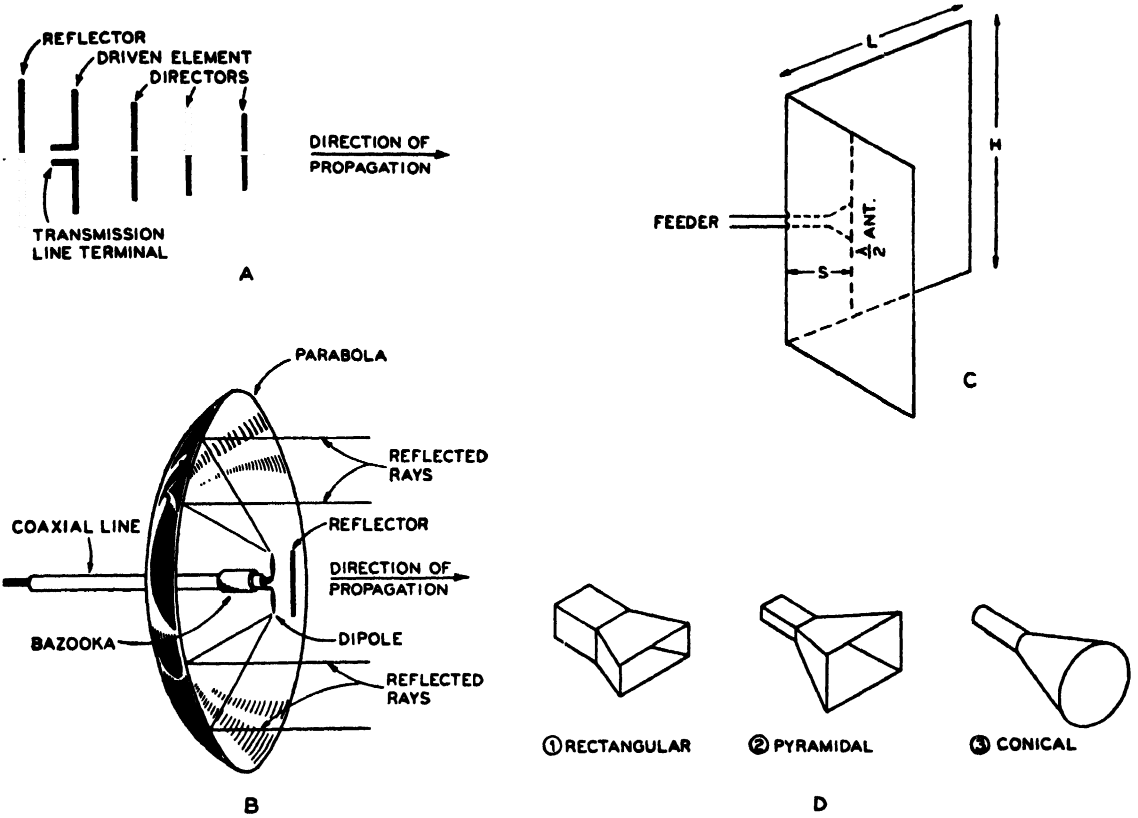

FIG. 17–49. A collection of directive microwave antennas.
A. Yagi array. B. Parabolic reflector. C. Corner reflector. D. Horn-type antenna.

watt. The parabola[10] possesses the characteristics that all rays striking the parabolic reflecting surface are reflected as parallel rays, as shown in Figure 17–49B. If an antenna is placed at the focal point of the reflector, the radiation from the antenna will be reflected as a beam.

A modification of the parabolic reflector consists of adding a hemispherical shield in front of the antenna to direct all the radiation back toward the parabolic surface, thereby eliminating direct radiation and producing a sharper beam. The radiation pattern of a parabolic reflector contains a major lobe, which is directed along the axis of revolution of the parabola and several minor lobes. The parabola of this type of antenna is large in comparison with the operating wave length and, in general, the larger the reflecting surface the narrower the beam.

17–55. Metallic Radio Lenses—As radar and radio relay communication systems were developed during the war, they created a demand for more and more sharply focused beams of microwaves which greatly stimulated the search for means of supplying them. The familiar "dish" antenna, in

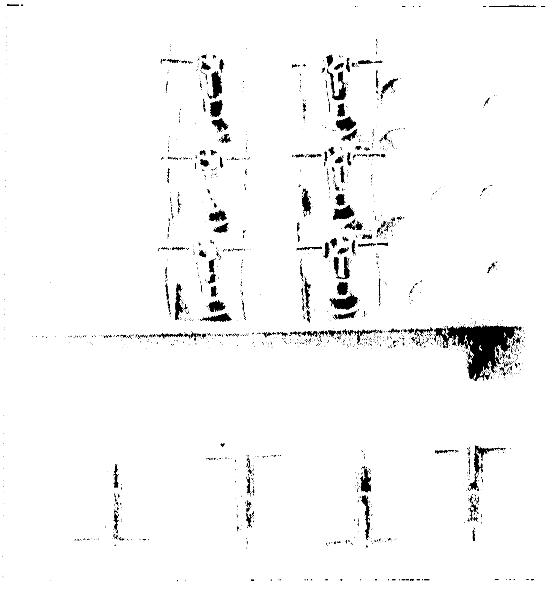

FIG. 17–50. Dipole antennas used in GCA assembled in special brazing fixture. (Courtesy Bendix Radio Engineer.)

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[10] Actually a parabola of revolution.

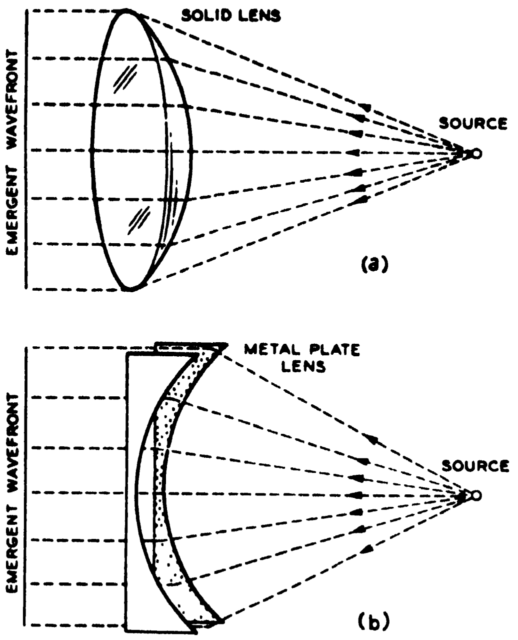

Fig. 17–51. Relative contours of a solid lens and of a metal plate lens.

which a beam is projected in nearly parallel lines after reflection from a parabola, had certain disadvantages in the way of tolerance requirements and shadowing effects. Lenses could undoubtedly supply the needed increase in beam-precision but in their existing solid form they were too massive for military uses.

It occurred to Winston E. Kock, a researcher of Bell Telephone Laboratories that an array of metal plates could be designed so as to focus radio waves just as effectively as a solid lens focuses them, if due regard be given to the fact that the edges of the wave front would be advanced instead of retarded in transit. Such a structure would be inherently easier to build, move, and maintain in service than an equivalent solid-type lens.

Figure 17–51 shows the relative contours of a solid or dielectric lens and of a metal plate lens both designed to convert waves from a point source radiator into a parallel-sided beam. Because of their opposite effects on wave front velocity they must be built of converse shape to produce the same focusing effect. The spreading waves approach the lens on a curved wave front. To bring them into a parallel beam, the metallic lens speeds up the edges of the beam relative to the center so that the wave front is flattened. The plates are enough longer at the sides than at the center to bring the laggard edges up in line with the center.

Figure 17–52 shows an antenna now being employed in the New York-Boston radio relay microwave system where the problem is to project and receive a precisely-directed beam between relay points, operating at 4000 mc, the lens, which is 10 feet square and encloses the front of a horn type radiator, has a stepped profile and a total beam width of less than 1.8°. Fed in through a wave guide in the rear, the waves spread out along the horn to the lens which focuses them into a pencil-beam. The horn-lens shown has exhibited a power gain of 12,000 over an isotropic radiator.

17–56. Corner Reflectors—The angular flat sheet type of reflector, also called the square-corner reflector (Figure 17–49c) provides better directivity than a parabolic reflector. A square-corner reflector with an aperture of one-half wave length can give a gain of about 8 db over a doublet. An aperture of twice this value or one wave length is necessary with a convertical parabolic reflector to obtain this amount of gain. This applies to parabolas with a focus-to-vertex spacing of about one-quarter wave length. It consists of two plane surfaces set at an angle of 90° with the driven element on a line bisecting this angle. The reflecting surfaces are not necessarily solid but can be made from wires spaced about 0.1 wave length apart.

As shown by Kraus, the gain of a 60° corner reflector, assuming infinite planes, is over 12 db and the gain of a 45° reflector even more. As the angle between the planes is decreased, the gain of the antenna can theoretically be increased to any desired amount. However, there is a real objection to the use of corner reflectors of less than 90° unless the spacing between the corner and the driven element is at least 0.5 wave length. This is so, since the radiation resistance of the half-wave driven element becomes very small as the angle between the planes is decreased, when small values of spacing are employed. If the spacing is about one-half a wave length, corners of less than 90° can be used advan-

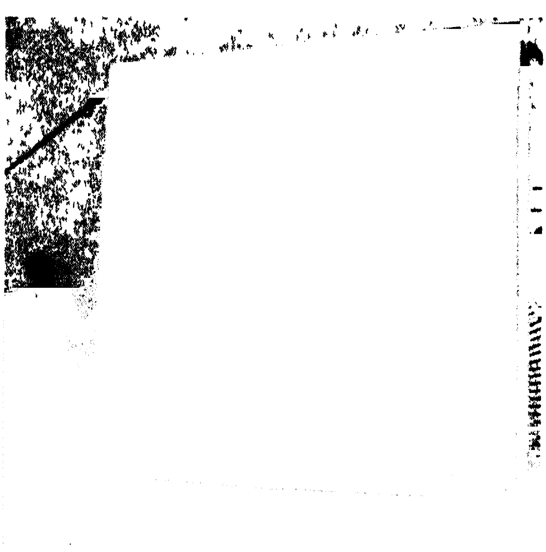

Fig. 17–52. Metal plate lens antenna.

tageously. A 60° corner reflector with a half-wave length spacing gives a computed gain of about 12.5 db. This is for infinite sides. If the sides are of such width that the aperture of the 60° reflector is about one wave length, the gain should still approach 12 db. In practice, a 90° reflector with a spacing of 0.3 wave length will produce a gain of about 8 db.

The corner reflector when supported vertically radiates vertically polarized waves. The corner and driven element can be turned horizontal to produce horizontal radiation.

17–57. Horn-type Radiators—The operation of horn-type antenna (Figure 17–49d) is very practical in the microwave region since the dimensions, which must be large compared with the operating wave length, do not involve unduly large physical sizes. Moreover, since they do not involve resonant elements, they have the advantage of being usable over a wide frequency range. In addition, they are readily adapted for use with wave guides, since they may serve dual purposes: (1) to match the impedance of the wave guide to the external space and (2) to produce directive wave patterns.

The shape of the horn together with the dimensions of the mouth measured in wave length determines the field-pattern for a given magnitude and the phase distribution of the field produced across the mouth of the horn. In general, the larger the opening of the horn, the more directive is the resulting field pattern. An aperture of approximately 5 wave lengths produces a radiated major-lobe of approximately 30°.

17–58. Effective Radiated Power—It should be kept in mind that the *total* power radiated by a multi-element or other form of directive antenna is not greater than that radiated by a simple dipole. The radiated power can be only as great as the transmitter power (less whatever losses occur in the system). The "gain" that is achieved is "effective" or useful power, that is, increased radiation in *useful* directions.

The term "effective radiated power" means the product of the antenna power (transmitter output power less transmission line loss) times (1) the antenna power gain or (2) the antenna field gain required.

It can be stated that, other things being equal, obtaining increased coverage by use of high-gain antennas is usually preferable to an increase in power.

17–59. Unidirectional Antennas for F–M and Television Broadcast Service—In their quest for the ideal antenna, one that would confine all of its radiation horizontal to the earth's surface, engineers have come up with several arrangements that serve to accomplish the purpose to the extent possible. Since horizontal polarization is standard for both F–M and television services the elements in the antenna must lie in horizontal positions.

There are now in use four general types of antennas designed for F–M and television service as follows: (a) the original Brown turnstile and the improved coaxial version, (b) DeMars turnstile and the three-quarter-wave spaced turnstile, (c) circular or ring antennas, and (d) square loop antennas.

17–60. Original Brown Turnstile—The first model of the Brown turnstile was constructed of metal rods a quarter-wave long attached directly to the supporting pole. Four such rods arranged in 90° spacing about the pole made up each layer or "bay." The complete antenna was composed of two to ten such layers, depending on the gain required, limitation of the supporting structure, etc.

The radiation pattern resulting from one layer of a turnstile antenna is that depicted in Figure 17–53. Since the center of the dipoles is at zero voltage with respect to ground, the dipole rods can be attached directly to the grounded metal pole and the spacing so chosen as to permit feeding the array at a point of proper impedance to match the transmission line. A single set of dipoles, of course, produces the characteristic figure-eight pattern shown in Figure 17–53A, which because of its directivity is not desirable for broadcast service; however, when the second set of dipoles are added and fed

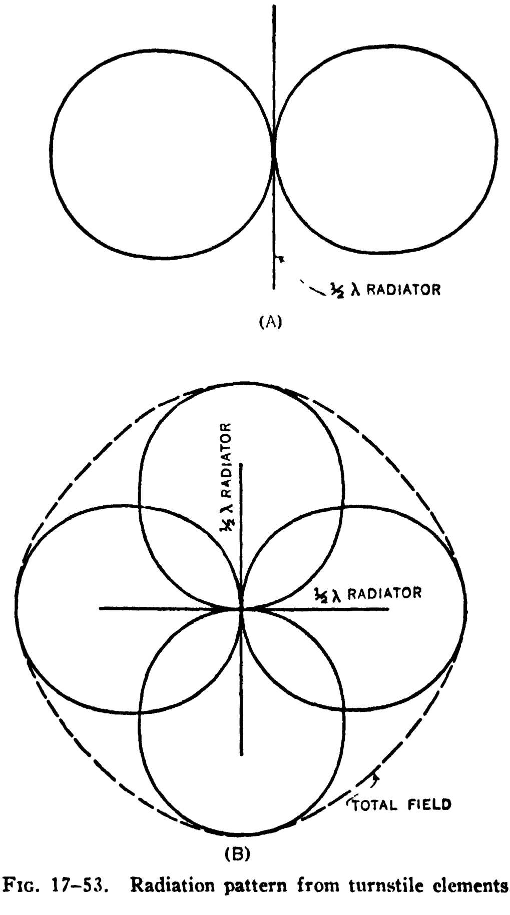

Fig. 17–53. Radiation pattern from turnstile elements.

an equal amount of power the pattern of Figure 17-53B results, which approaches a circle. More bays increase gain in the horizontal plane at the expense of high-angle radiation.

If the antenna is constructed of several bays of dipoles in one plane, these must be fed an equal amount of power of the same phase. This is accomplished by spacing the bays or layers a half-wave length apart and crossing over or transposing the open transmission line between bays, thereby counter-balancing the phase shift that occurs along the line between layers. Two such transmission lines, one for each set of dipoles, are required and are twisted about the pole as they go to the top and supported by stand-off insulators. The lines are fed at the base of the pole by oppositely phased currents by one of several methods.

The matching of the feed lines in this design is extremely critical and the open-wire lines are subject to large changes when ice formation takes place Ice increases the wind resistance and is detrimental to the radiating system. Coaxial lines have therefore been substituted. Each radiating element in the later design consists of a rod rigidly mounted to the tower by means of a steel band, an outer sleeve which is insulated from the rod and a section of concentric line which acts as a phase shifting and impedance matching device. It will be recalled that phase shifting was accomplished in the original design by transposing the open transmission line between layers. The concentric matching section is fastened along the sleeve which is the actual radiator.

The following advantages are claimed for the coaxial fed turnstile:

(a) The antenna can be completely "pre-tuned," while being completely assembled in production.

(b) Since phasing is accomplished at the radiators, there are no phasing adjustments to be made at the bottom of the supporting structure and all line impedances are matched, resulting in no standing waves on the lines.

(c) The frequency range, both as to line termination and field intensity, is wider than is required for wide band F-M.

17-61. "Super-Turnstile"—An antenna shown in Figure 17-54 has been developed by RCA for F-M and television service which is, in a sense, an improved version of the original Brown turnstile and has accordingly been dubbed the "Super Turnstile." This antenna features a broad-band operating characteristic, simplified feed system, and durable construction. A single antenna design will operate well over the entire F-M broadcast band, 88 to 108 mc, and for any transmitter power up to 20 kw.

The most noticeable feature of the new Super Turnstile is the use of "current-sheet" radiators in place of the simple dipole arms previously described. In the original model, the batwing- or elephant-ear-shaped elements were solid pieces of sheet metal; hence, the term "current-sheet." Subsequently, it was found that the same results could be achieved with an open framework of steel tubing with cross rods of solid steel rod, thus reducing the wind resistance. The effect achieved with the current-sheet radiators is to broaden the antenna characteristics so that the impedance reflected in the transmission line will be nearly equal to that of the line itself over a frequency range of plus or minus 20 percent, which is nearly twice the F-M band of 88 mc to 108 mc. The bandwith permits transmission of both sound and picture programs from the same antenna. The "current sheets" are attached to the pole (ground) at top and bottom. The r-f currents

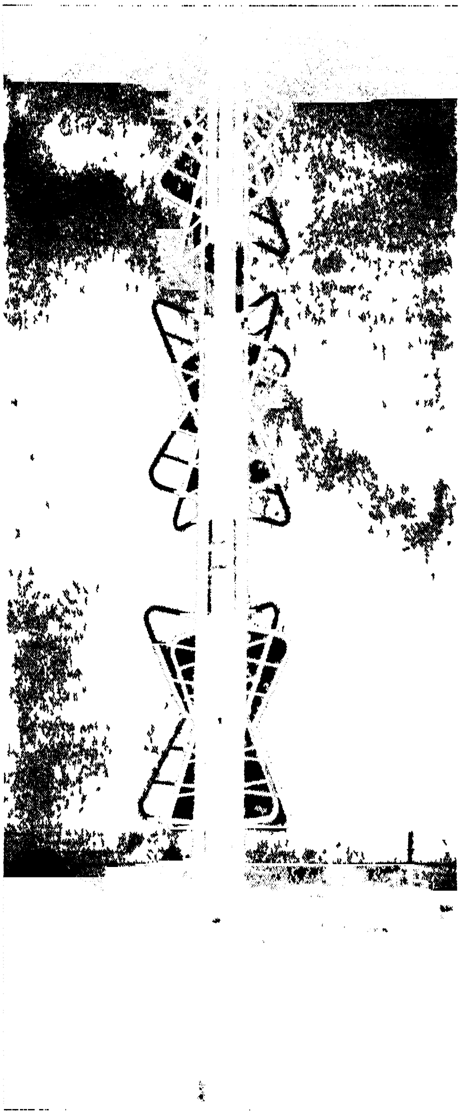

FIG. 17-54. RCA "super turnstile."

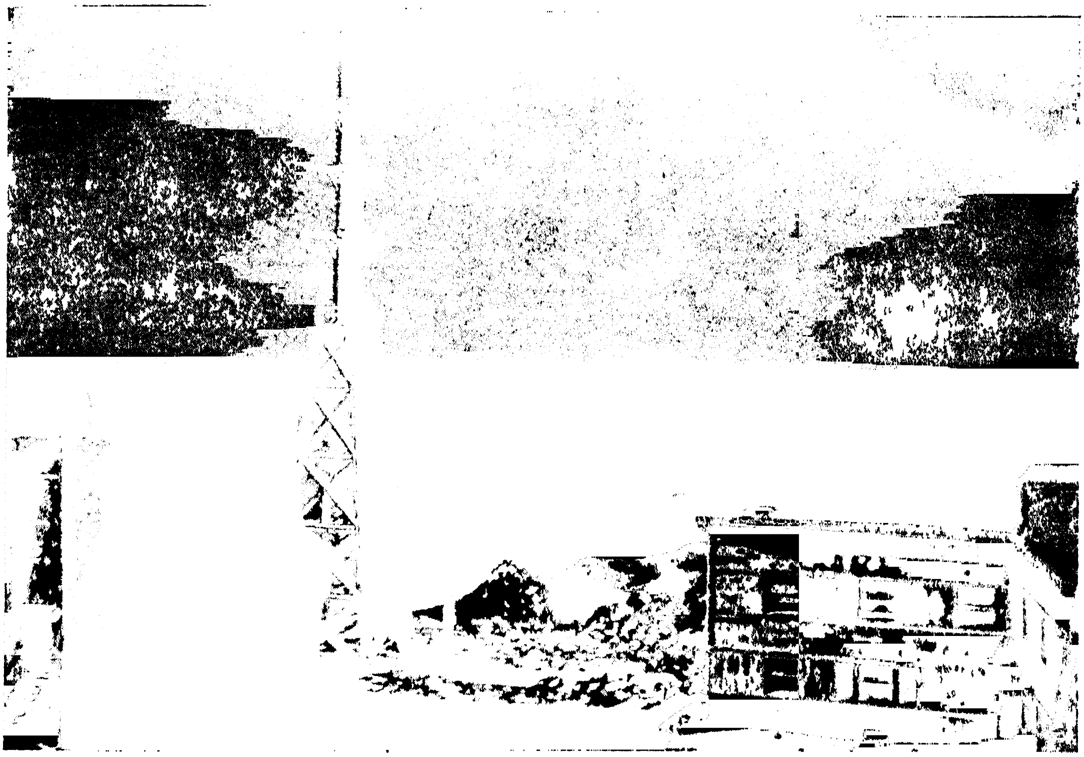

FIG. 17–55. DeMars turnstile antenna, Mt. Washington, N. H., employed by Yankee network F-M station.

in the radial members radiate more or less proportionally to the length of the member and to the magnitude of the current in the member. The longer members have a greater effect in radiation than the short ones; hence, a close approximation to the radiation pattern of two simple dipoles, spaced one-half wave length apart, is obtained.

The vertical steel tube of the current-sheet is at ground potential on the ends; consequently, a heater unit can be connected into this vertical tubing. This will prevent ice formation between the current-sheet and the pole, this being the place that would undergo an impedance change due to ice formation. The antenna can withstand a half-inch ice coating under high wind conditions.

17–62. DeMars Turnstile—The Yankee Network employs a modified version of the Brown turnstile developed by DeMars which uses separate coaxial feed lines for each radiator. The coaxial lines extend down the tower to a "phasing room" at the base. The most notable of this version of the turnstile antenna is used on Mt. Washington in New Hampshire and is shown in Figure 17–55. Because of the extreme weather conditions including violent gales and continual ice formation, truck springs are used as the radiating elements. The "phasing room" at the base of the tower permits critical adjustments of phase under shelter where they can be done accurately.

17–63. Circular Antenna—The circular antenna is essentially a folded dipole antenna bent around into a circle. The folded dipole in its simplest form consists of two half-wave radiators, one of which is broken at the center and power fed to the system at this point, the characteristics of which were explained under the section captioned "Folded or Multi-Wire Doublets." Since the two radiators are mounted very close together, the currents in them flow in the same direction and current distribution on both is the characteristic of a half-wave dipole with a current loop and a voltage node at the center. Since the voltage is zero at the center, the unbroken radiator can be attached directly to the supporting pole at this point. The pole is grounded to provide lightning protection for the antenna. The ends of the lower portion of the folded radiator can be fed power by an open balanced transmission line or by a pair of concentric lines operating 180° out of phase. A single radiation of this type produces the figure of eight pattern in the horizontal plane like that of a single turnstile dipole. It is not suited for broadcast service. To achieve a uniform or circular pattern of distribution, the dipole is bent around to a circle and a pair of large metal plates are fastened at the folded points as shown in Figure 17–56. The addition of the plates has the effect of adding end capacity to the radiators and effects a fairly uniform distribution of

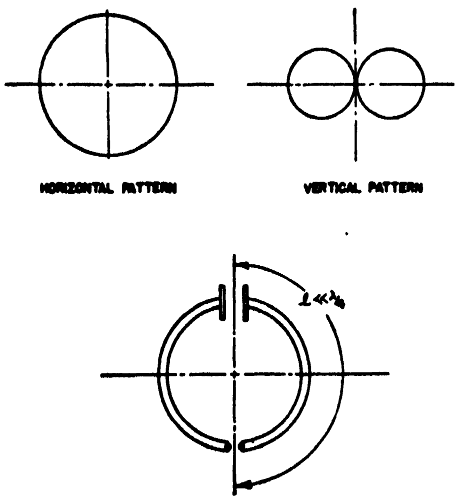

Fig. 17-56. Horizontal and vertical radiation patterns of simple loop antenna.

current around the loop and the radiation pattern approaches a circular pattern. The circular antenna has a higher gain per layer than the turnstile; however, in order to keep down the mutual impedance the layers must be placed a full wave length apart. Consequently, the gain per height is less than with the turnstile when more than one layer or bay is used.

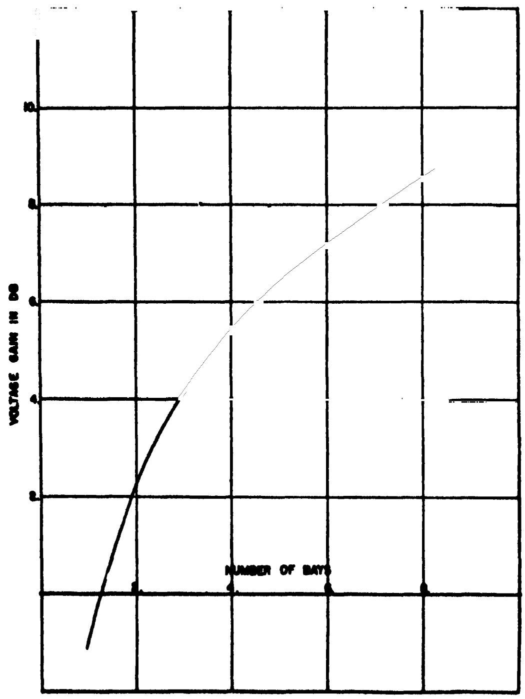

Fig. 17-57. Gain of F-M circular antenna, compared with vertical half-wave dipole, for different numbers of bays spaced a wave length apart.

Figure 17-57 shows the gain of a circular antenna, compared with a vertical half-wave dipole for different numbers of bays spaced a wave length apart.

17-64. Square-loop Antennas—Figure 17-58 shows the arrangement of one layer of a "square-loop" antenna, consisting of four dipole radiators. The dipoles may take the form of folded or simple dipoles fed at the center, according to how the impedance matching is obtained. The gain per layer of the square-loop antenna is greater than either the turnstile or the circular antenna since each layer has effectively twice as many radiators as the turnstile. Since the vertical radiation is low, the layers can be mounted at half-wave intervals.

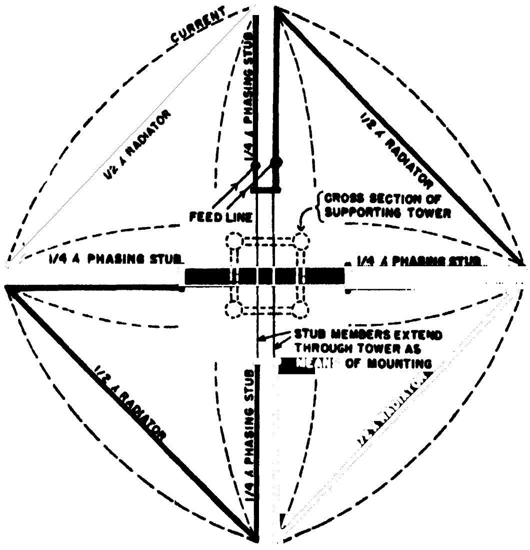

Fig. 17-58. Arrangement of "square-loop" mounted on a tower.

The square-loop antenna can be used in places where it is impractical to erect a pole on top of a building or the configuration of the building prevents it. The elements of the antenna can be attached directly to the four sides of a building.

Figure 17-59 shows another type of square loop antenna developed by the Federal Telephone and Radio Laboratories[11] in which the metallic supporting structure as well as the radiators themselves form part of the coaxial feeding system. By proper choice of surge impedance of these two short lengths of line in the supporting arm and the radiator itself, the desired impedance of 50, 70 or 100 ohms pure resistance may be obtained to match commercially available coaxial transmission lines having these values of surge impedance.

At very high frequencies and ultra-high frequencies the most practical way of expressing the input impedance is in terms of the standing waves on the transmission line feeding the antenna. Figure 17–60 shows the variation in standing-wave-ratio (SWR) as the frequency is varied. On the strength of such measurements—the Federal Telephone and Radio Corporation have adopted the square loop antenna for use in the F–M broadcast service utilizing the same-sized structure (per bay) over the entire F–M band (88 to 108 mc).

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[11] Arnig G. Kandoian, "Three New Antenna Types and Their Applications," *Proc. I.R.E.*, Vol. 34, February, 1946.

The power gain, as a function of both the number of loops and spacing between loops, is shown in Figure 17–61. Two important facts are evident:

1. A power gain of 20 may be feasible if a sufficient number of loops is stacked.

2. While the optimum gain occurs when loops are a wave length apart (i.e., 360 electrical degrees), this spacing is not critical and may vary from 300° to 420° with only slight reduction in gain.

It should be noted that the gain as expressed in the curves is with respect to a single loop and it is necessary to multiply by .9 to obtain the gain with respect to a half-wave dipole which is generally done in engineering practice.

The vertical radiation pattern of 2, 4 and 8 stacked loops is shown in Figure 17–62.

An interesting electrical characteristic of these antennas is that the input impedance of each pair of loops is designed to be 50 ohms, so that they can be fed by a standard $1\frac{5}{8}$-inch or $3\frac{1}{8}$-inch coaxial line. How this is done is shown in Figure 17–63. As illustrated, all impedance matching is achieved within the loop via the two quarter-wave transformers—Z01 and Z02. A perfect match occurs, however, only at a frequency where the transformers are exactly a quarter of a wave in length. As the frequency is varied around this point, the impedance changes. However, this impedance change is such that the resistance component is low and the reactive component is relatively high. It is then a

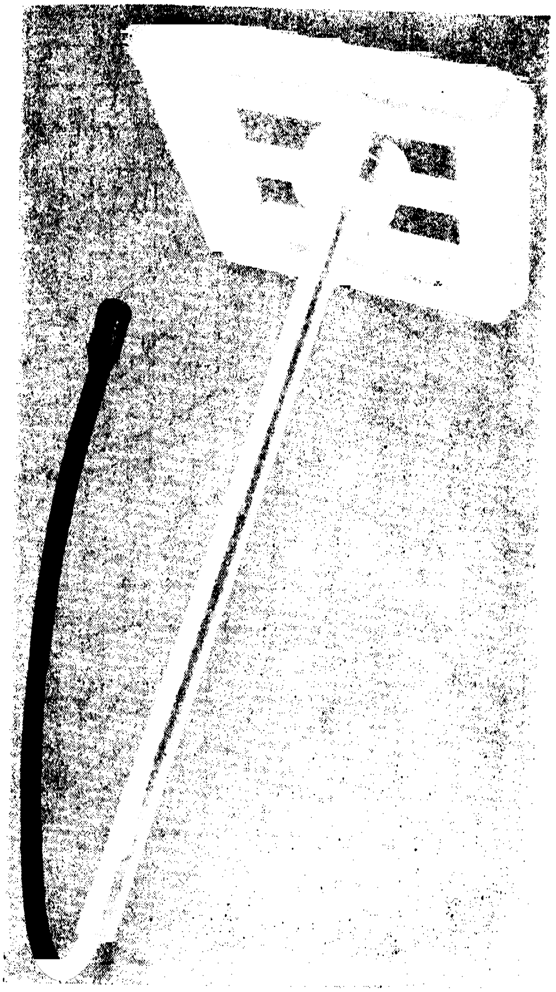

FIG. 17–59. Federal square loop antenna. (Courtesy IRE and Federal Telephone and Radio Laboratories.)

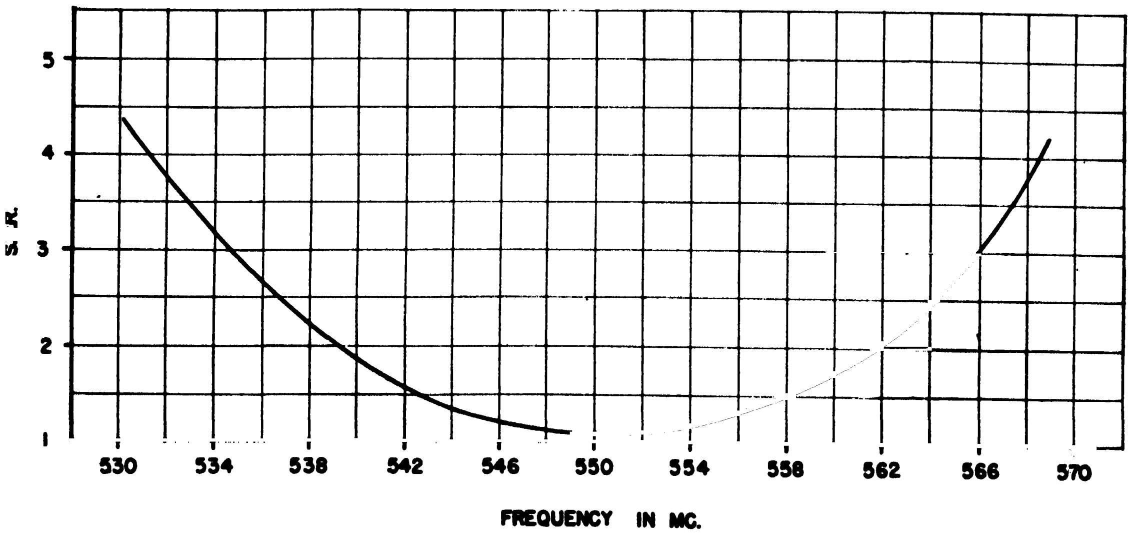

FIG. 17–60. Frequency versus standing wave ratio, square loop antenna. (Courtesy IRE and Federal Telephone and Radio Laboratories.)

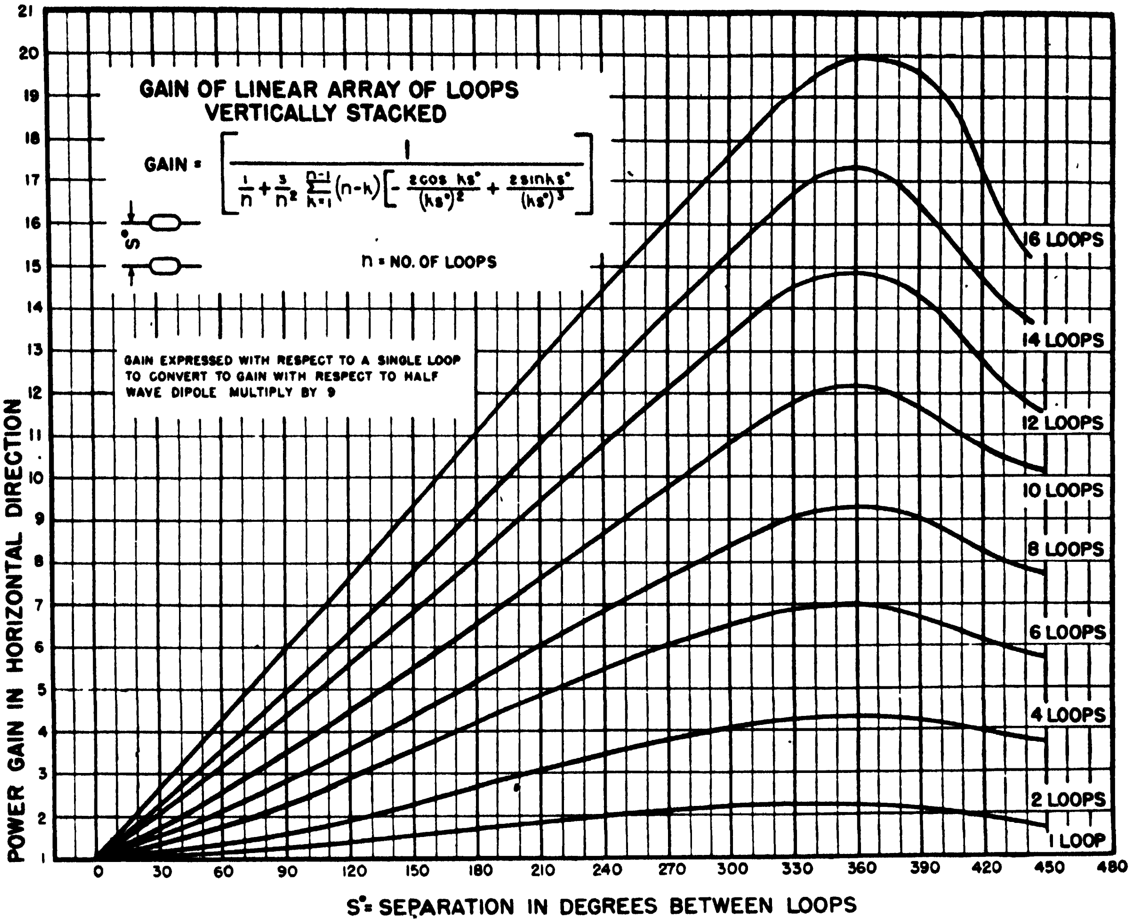

FIG. 17–61. Gain of linear array of loops vertically stacked.

simple matter to use a reactive stub to bring the resistance component back to 100 ohms and cancel out the residual reactance. Thus the loop can be made to operate at any F–M frequency. This latter characteristic, plus the noncritical nature of the spacing between loops, combines to give the loop very favorable mechanical and manufacturing properties.

17–65. Western Electric 54–A Antenna [12]—The Western Electric 54–A antenna is designed to radiate horizontally polarized radio waves particularly for use by frequency modulation broadcast stations operating at carrier frequencies between 88 and 108 mc and at power levels up to and including 50 kw.

The antenna comprises an array of two or more vertically stacked radiating units. Each radiating unit is composed of a cluster of four curved elements which in plan view forms a symmetrical shape similar to a four-leaf clover. A radio frequency voltage applied between the junction of the four elements and their ends causes in effect a ring of uniform current which produces a circular radiation pattern about the axis of the ring. The antenna has a power gain ranging from about two to about five, depending on the size of the antenna (number of radiating units) selected.

The distribution of the radiated energy about a typical 54–A antenna of the five-unit size is shown in Figure 17–64. The signal intensity is greatest in the direction of the horizon (0°) and is substantially less at higher elevations. The pattern becomes narrower and the gain higher as the number of units and length of the antenna are increased—*all provided that the instantaneous currents in the individual radiating units are established and maintained in their proper relationships.*

Maximum gain occurs when the instantaneous currents in all radiating elements are in time phase and of equal amplitude. These current relationships are easily and correctly established at the station's operating frequency with the 54–A antenna at the time of installation *by methods which do not require field or factory tuning.* All radiating elements are connected by means of simple clamps at half wave length intervals to a 3-inch diameter feed

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[12] Courtesy Western Electric Co.

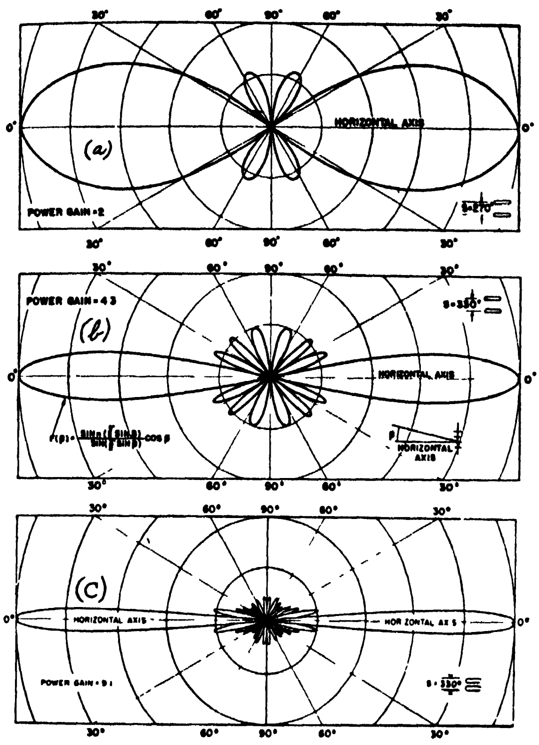


FIG. 17–62. Vertical radiation patterns.

conductor which is centrally located within the tower structure. The tower itself serves as the return or outer conductor of the feed line. The usual phase reversal occurring along such a feed line at half wave length intervals is compensated for by merely reversing the mounting position of the radiating elements in adjacent units. This simple installation procedure assures the correct current phasing for maximum gain at the station's operating frequency.

Four small diameter vertical cables are used to nullify vertically polarized radiation which might otherwise be radiated at high angles. This type of radiation is usually caused by spurious currents flowing in vertical structural members as the result of coupling between the structure and radiating elements.

The impedance of the 54–A antenna array is matched to the impedance of a coaxial transmission line by means of a unique low-loss transformer which utilizes the base section of the tower and antenna feed conductor. This transformer can be adjusted over a wide impedance range and it is set to the proper adjustment at the time of installation.

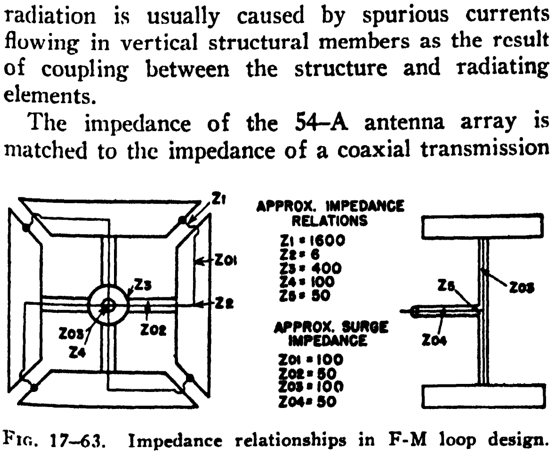


FIG. 17–63. Impedance relationships in F-M loop design.

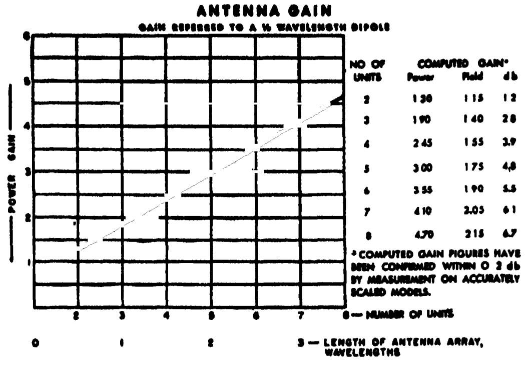
Provisions are made for the installation of electric heating cables inside of the tubular radiating elements for sleet melting. Since one end of each radiating element is connected directly to the tower structure, the need for r-f filters in the heater power circuit is avoided.

Provisions are also made for the mounting of a 300 mm aircraft warning beacon light on top of the tower structure.

17–66. Directional Horizontally Polarized Broadcasting Antenna Arrays—Under certain conditions directional arrays for F–M broadcasting might be employed to advantage, as, for example, should it be desirable to place the radiator next to the seacoast or at the end of a populated valley, taking advantage of a near-by hill or mountain on which to locate the radiator. While directional transmission of vertically polarized waves is commonplace in the 500–1600 kc broadcast band, less has been done toward directional broadcasting of horizontally polarized waves in the F–M and television bands. Engineers of the Western Electric Company have therefore experimented with 1⁄10 scale models of the type 54–A clover-leaf and have shown that a considerable variety of radiation patterns may be obtained by using 2 complete 54–A radiators (antenna arrays), properly spaced and excited in proper phase relationship. Two such patterns are shown in Figures 17–65 and 17–66. Figure 17–65 is a good example of how such an array might be used to serve an area which is long and narrow. This pattern is obtained with two 54–A clover-leaf antenna arrays spaced 5 wave lengths apart and excited in phase. Under these conditions the array power gain in the maximum direction is 2, so that an array comprising two eight-element clover-leaf antennas, each having a power gain of 4.7, would give a maximum power gain of 9.4.

In the case of F–M broadcast service it would probably be unnecessary to provide the deep nulls or minima shown in Figure 17–65, except in the case of attempting to protect against interference to another station. Appropriate adjustments of the array permit less pronounced nulls with only a small reduction of signal intensity in the maximum direction.

The pattern shown in Figure 17–66 could be used if the transmitter site is near one side of the area to be served. Maximum signal intensity would be radiated in the direction of the greatest number of listeners and minimum signal in areas in which there may be no listeners. The spacing of the two clover-leaf antenna towers in this case is 0.325 wave



NO OF UNITS	COMPUTED GAIN* Power	Field	db
2	1.30	1.15	1.2
3	1.90	1.40	2.8
4	2.45	1.55	3.9
5	3.00	1.75	4.8
6	3.55	1.90	5.5
7	4.10	2.05	6.1
8	4.70	2.15	6.7

*COMPUTED GAIN FIGURES HAVE BEEN CONFIRMED WITHIN 0.2 db BY MEASUREMENT ON ACCURATELY SCALED MODELS.

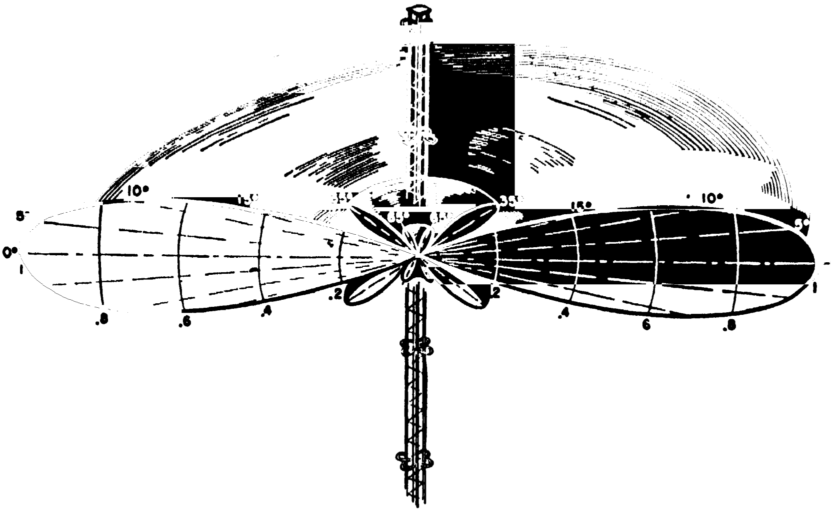


Fig. 17–64. Computed radiation pattern for a 5-unit Western Electric 54A antenna

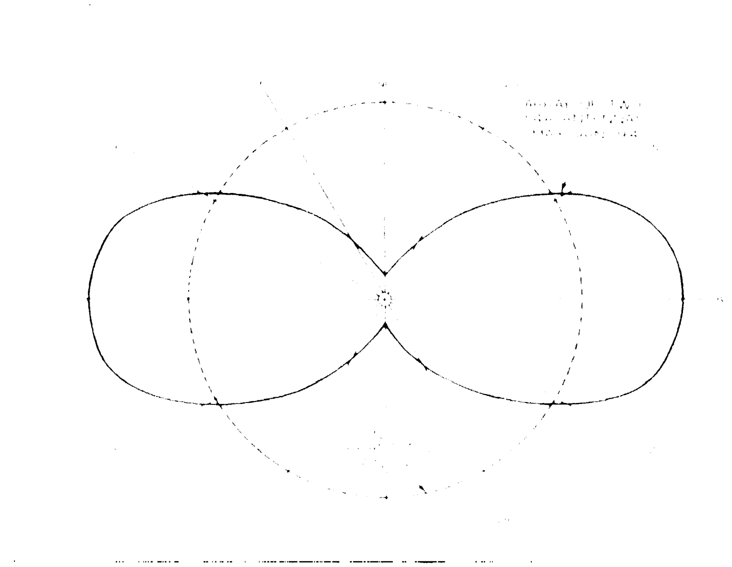


Fig. 17–65. Pattern when area to be served is long and narrow. Maximum array gain is 9.4.

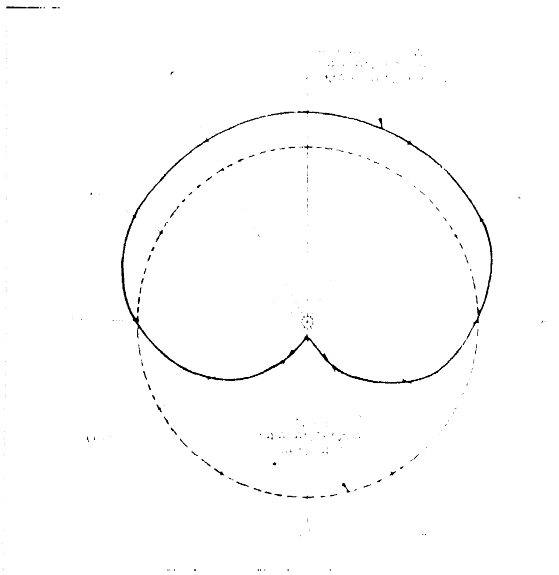


FIG. 17–66. Pattern when transmitter site lies near one side of area to be served. Maximum array gain here is 6.6.

length and the relative current phasing is 117°. It will be observed that the maximum intensity lies along the projection of the axis of the array, and the minimum is in the opposite direction.

The maximum gain is 6.6 It will be noted that the field intensity is considerably greater than that due to a single 54–A antenna over 180° (compass directivity) while considerably reduced in the other 180°.

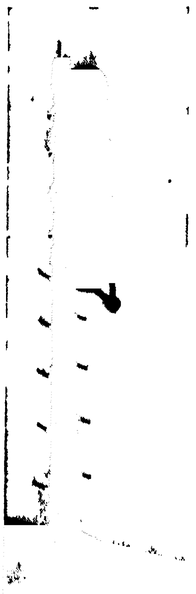


FIG. 17–67. The Alford slotted antenna.

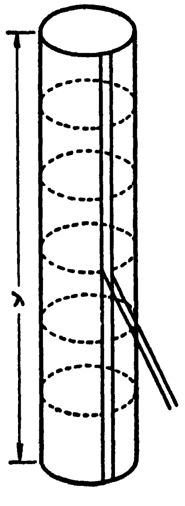


FIG. 17–68. Slotted antenna equivalent to a stack of small in-phase loops.

17–67. The Alford Slotted Tubular Antenna—Figure 17–67 is a photograph of a new horizontally polarized antenna developed by Andrew Alford for the Finch Telecommunications F–M station WFGG, operating on 99.7 mc.

The antenna is essentially a sheet of metal bent into the form of a cylinder which is not quite closed, hence a straight narrow slot extends full length of the cylinder, or tube. The metal cylinder is provided with a metal bottom, but no top. Protection from weather is provided by covering the open top with a molded fiber-glass dome and the slot is closed by a fiber-glass strip. Electrically, a one-slotted

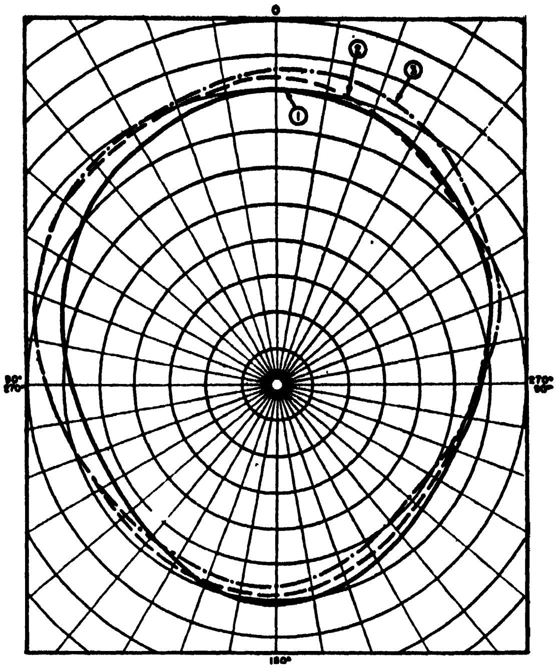


Fig. 17–69. Horizontal radiation pattern, plotted in millivolts per meter. (Courtesy "Communications.")

cylinder behaves like a half of a loaded waveguide. The dimensions are chosen so that the waveguide operates near the cutoff. The phase velocity, therefore, is greater than that of light. The result is that across the slot is developed a distribution of potential which is very nearly in the same phase throughout the entire length of the slot with guide half wave length being much longer than the half wave length in space. The currents which are produced by the potential existing across the slot flow in horizontal circles around the cylinder so that the latter operates something like a stack of small, inphase loops, as shown in Figure 17–68, radiating horizontally polarized waves.

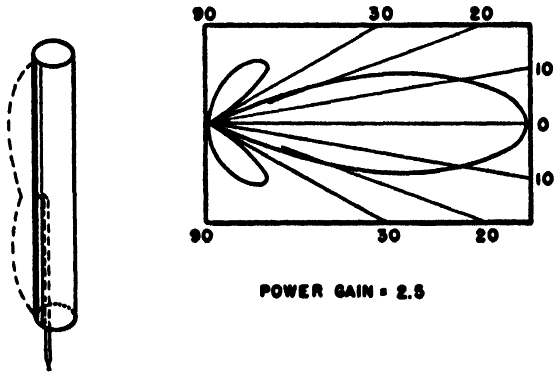


Fig. 17–70. Vertical antenna pattern of a dual tubular antenna at right with open ends joined as shown at left. (Courtesy "Communications," July, 1946, Chas. Jones, "Slotted tubular antenna for 88 to 108 megacycles."

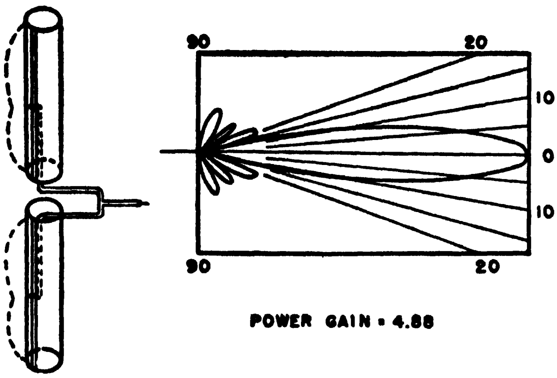
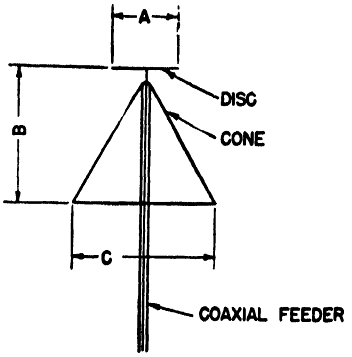


Fig. 17–71. Double rocket arrangement energized in the same plane. Vertical pattern at right. (Courtesy "Communications," July, 1946, Chas. Jones, "Slotted tubular antenna for 88 to 108 megacycles."

The antenna is energized by a coaxial feeder brought into the cylinder through the bottom flats and is continued along one side of the slot to the top of the antenna where it is terminated with an end-seal insulator. The impedance of the antenna at the feed point is about 165 ohms with a negative reactive component. A line transformer is employed to match the antenna to a standard 70-ohm or 51.5-ohm concentric transmission line. The outer conductor is metallically connected to the cylinder at the end seal and at several equally spaced points. The inner conductor is brought out through the end seal and is connected to the opposite edge of the slot. The radio-frequency voltage between the inner and outer conductors is thus applied between the opposite edges of the slot.



CUTOFF FREQ.	A	B	C
90 MC.	18"	24"	20"
200 MC.	9"	12¼"	14"

Fig. 17–72. The discone antenna schematic. (Courtesy IRE and Federal Telephone and Radio Laboratories.)

The diameter of the cylinder is dictated by the r-f voltage distribution. The over-all length of the cylinder equals approximately one wave length at the operating frequency. The voltage distribution

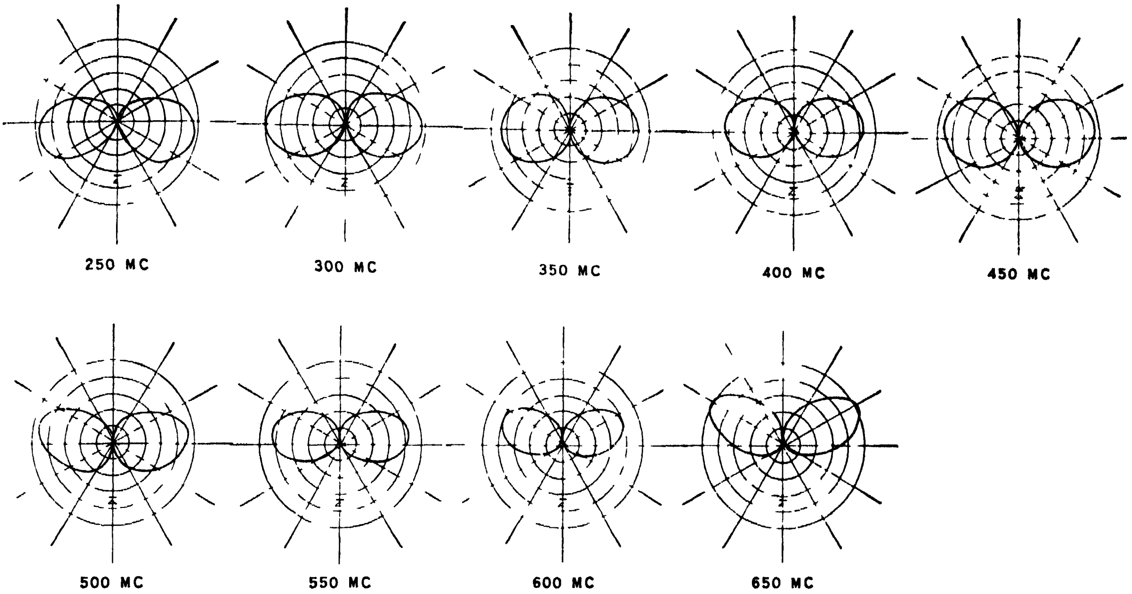


FIG. 17-73. Discone antenna—cutoff 200 mc, vertical patterns.

is not sinusoidal, but comes closer to the ideal uniform distribution. The horizontal radiation pattern is shown in Figure 17-69.

The horizontal pattern not being perfectly circular, comparison between the slot antenna and a standard half-wave antenna is made on the basis of the equivalent pattern. The equivalent pattern has a radius equal to 1/1.24 of the maximum of the actual pattern. On this basis the power gain of this antenna is 1.6.

When calculated according to the F.C.C. Standards of Good Engineering Practice, the variations from the circular almost disappear and the patterns appear to be circular.

Two antennas of this type can be stacked to achieve a power gain varying from 2.5 to 4.86. The vertical pattern of two different arrangements of dual tubular antennae are shown in Figures 17-70 and 17-71.

17-68. The Discone Antenna—The Discone

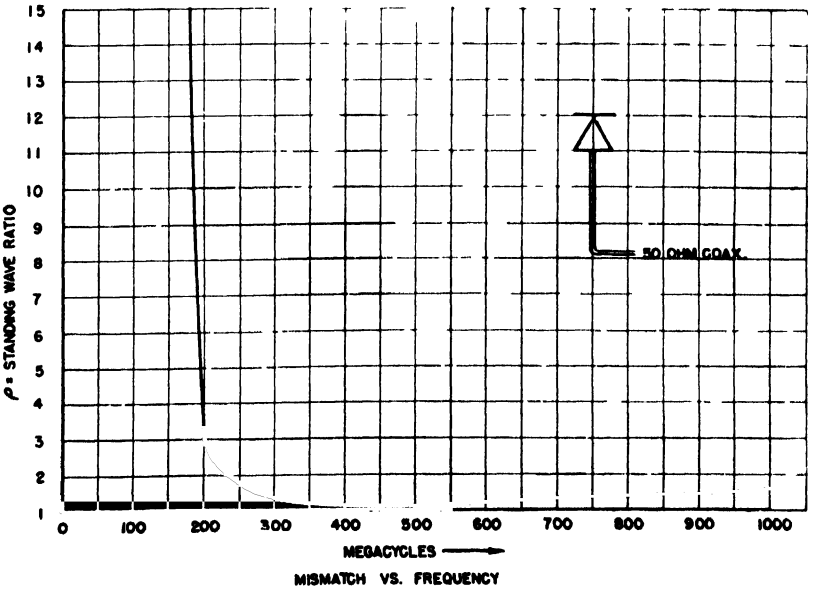


FIG. 17-74 Discone antenna—cutoff 200 mc. (Courtesy IRE and Federal Telephone and Radio Laboratories.)

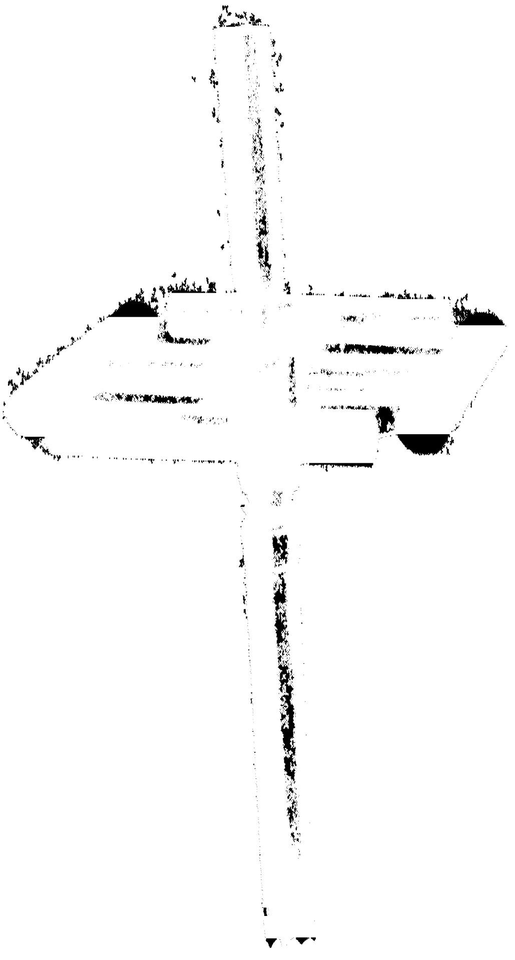


Fig. 17–75. Type III antenna, 1200 mc. (Courtesy IRE and Federal Telephone and Radio Laboratories.)

antenna is a development of the Federal Telephone and Radio Laboratories.[13] As the name suggests, it consists of a disk and a cone whose apex approaches and becomes common with the outer conductor of the coaxial feeder at its extremity. The center conductor terminates at the center of the disk which is perpendicular to the axis of the cone and r-f transmission line. Figure 17–72 shows a schematic of the Discone antenna with a tabulation of typical dimensions.

The Discone antenna, like a vertical dipole, radiates in all directions in the horizontal plane. Therefore, it is said to have an omnidirectional pattern of radiation. Its most important characteristic is its ability to operate over a very wide band of frequencies without a substantial change of either input impedance or radiation pattern. The change of impedance versus frequency is very much less than any ordinary dipole of fixed length.

This antenna may be visualized as a radiator intermediate between a converted dipole and electromagnetic horn. At the low end of its operating band, it behaves very much like a dipole and at high frequencies becomes essentially a horn radiator.

Analyzing the circuit characteristics of the Discone antenna it behaves essentially as a high-pass filter. It has an effective cutoff frequency below which it becomes very inefficient, causing standing waves on the coaxial transmission line. Figure 17–73 shows typical measured radiated patterns of a Discone antenna, designed to cutoff at approximately 200 mc. Only a little mismatch of impedance occurs above the cutoff frequency; consequently, the radiation pattern remains substantially uniform over a wide range of frequencies. It will

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[13] A. G. Kandoian, "Three New Antenna Types and Their Applications," *Proc. I.R.E.*, February, 1946.

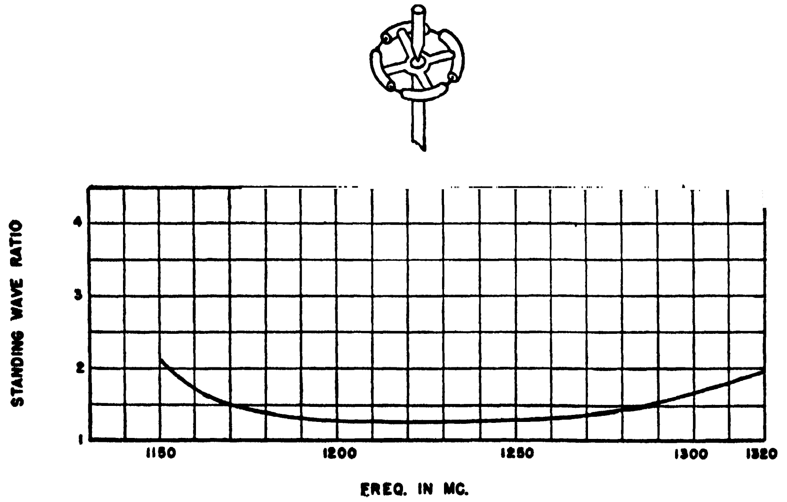


Fig. 17–76. Loop dipole combination. (Courtesy IRE and Federal and Telephone Radio Laboratories.)

be observed that at the high-frequency end the radiation pattern starts to turn upward.

The coaxial feed line participates somewhat in the over-all radiation much in the same way that it does in all cases of vertical radiators fed with a coaxial line, because of induced currents in the supporting structure and line. The amplitude of the induced currents in this case is of the order of 5 percent of the main antenna current and, hence, causes "scalloping" of the radiation pattern of approximately ± 5 percent.

It has been suggested that suppression of this affect might be secured by clamping radial rods on the supporting structure below the open end of the cone, thus eliminating coupling between the antenna and the supporting structure.

Figure 17–74 shows typical mismatch versus frequency relations of a Discone antenna fed by a 50-ohm coaxial feeder. This may also be read as standing wave ratio versus frequency.

The author in his paper suggests that the cone of the antenna may serve to house the transmitting and receiving equipment.

17–69. Combined Vertical and Horizontal Antennas—Another experimental development of the Federal Telephone and Radio Laboratories is a combined loop and vertical radiator termed an "electric-magnetic" dipole (Figure 17–75). The vertical radiator is located at the transmission line junction at the center of the loop and perpendicular to the plane of the loop. Since the loop radiates horizontally polarized waves, and the vertical dipole vertically polarized waves, there is at every point in space equal amounts of horizontal and vertical polarized waves, provided the power is equally divided between the two antennas. Since the relative phase and amplitude of the currents in the vertical dipole and loop can be controlled, it is possible to produce any type of polarization, i.e., horizontal, vertical, circular or the most general case, elliptical. Wide band transmission is possible as is shown by Figure 17–76.

Experiments conducted with this type of antenna have shown that it is possible to secure a field strength independent of the orientation of the receiving dipole, provided the latter is kept perpendicular to the direction of propagation.

This type of antenna may prove very useful in ultra-high frequency communication networks where considerable fading may exist due to changes in the medium of propagation since in cases of severe fading, the probabilities are that both horizontal and vertical components of the electric field will not vary at the same rate and at the same time because they are affected differently by the reflecting medium between transmitters and receivers.

In the case of broadcasting service, if circular polarization were used at the transmitting end, it would permit the use of either a vertical or horizontal dipole at the receiving end, depending on convenience or architectural acceptability.

Field tests have been conducted to determine the feasibility of such a method of transmission in the F–M broadcast service. The engineering staff of the United Broadcasting Company of Cleveland, Ohio, under the direction of Carl E. Smith reported the results of their experiments in the Cleveland area to the F.C.C. on October 1, 1946. The transmitting antenna shown in Figure 17–77 was designed to radiate any type of elliptical polarization with controls to produce circular, diagonal, vertical, or horizontal polarizations.

The term *circular polarization* as used in the tests and report means the idealized case of elliptical polarization in a plane at right angles to the direction of propagation. In this plane the electric vector is of constant amplitude and rotates at the carrier frequency in a clockwise or counter clockwise direction. In general, elliptical polarization will actually be produced; however, circular polarization may be approached.

The report, which is too long to be reproduced, concludes that:

"*a.* It is feasible to construct a transmitting antenna that will radiate elliptical polarization which closely approaches circular polarization.

"*b.* The propagation characteristics of circular, vertical, and horizontal polarizations are quite similar in nature, making it feasible to match service area contours with any chosen polarization.

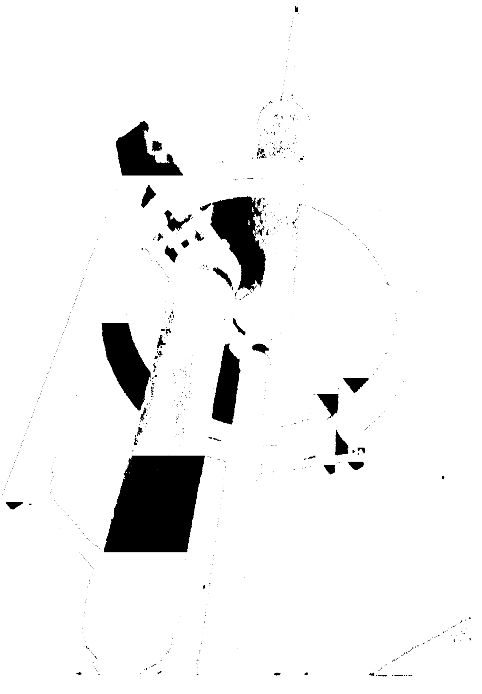


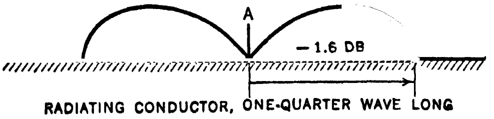
Fig. 17–77. Transmitting antenna employed by United Broadcasting Company for purpose of conducting circular polarization tests.

"*c.* The adoption of circular polarization as the Federal Communications Commission standard for FM and TV broadcasting stations would have the following effects:

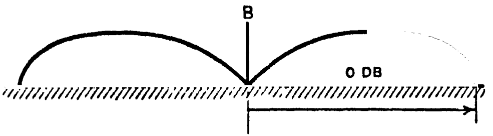
"(1) increase the installation and operating cost to the broadcaster,
"(2) decrease the antenna requirements for the home and car radio receiver,
"(3) materially increase the possibility that a receiving antenna located at random will provide satisfactory reception,
"(4) not alter the allocation problem."

17–70. Vertical VHF Antennas and Arrays— In the emergency and other mobile and fixed services operating above 30 mc, communication is in general confined to vehicles equipped with whip type antennas. This, plus the fact that vertical polarized antennas are nondirectional, dictates the choice of vertical antennas for use at the fixed stations of such services. The coaxial antenna invented by Arnold Bailey of the Bell Laboratories is used extensively for this purpose. This device deserves somewhat detailed discussion, especially as to its background.

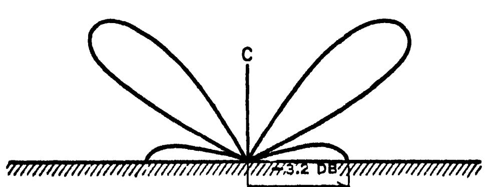
The transmitter supplies power to the concentric antenna by means of concentric transmission lines. In these lines the useful current is carried by two paper-thin metallic conducting surfaces: first, the thin surface of the ¼-inch copper inner conductor which may be considered as the outgoing conductor, and, second, the inside thin surface of the ⅞-inch copper sheath which may be considered as the return conductor. The penetration of the current in these surfaces is extremely small at ultra-high frequencies. A third conducting surface, namely, the outer surface of the ⅞-inch cooper sheath, is present, but plays no part in the transfer of energy in the idealized case. Unfortunately, when a concentric line is placed in a vertical position, i.e., when it is installed alongside the steel supporting pole and terminated at the top of the pole by the antenna section, adverse radiation takes place from both the *pole* and the metal surface of the transmission *line*.



RADIATING CONDUCTOR, ONE-QUARTER WAVE LONG



RADIATING CONDUCTOR, ONE-HALF WAVE LONG



RADIATING CONDUCTOR, THREE-QUARTER WAVE LONG

Fig. 17–78. Vertical directivity patterns for grounded vertical antennas.

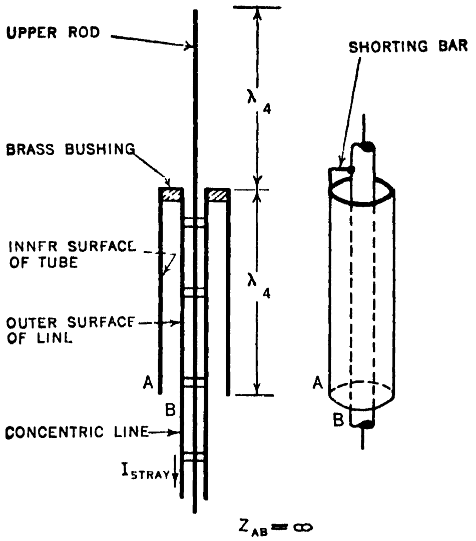


Fig. 17–79. Method of terminating lower end of coaxial antenna in a very high impedance.

This radiation results from the fact that the useful r-f current in the inside conductor of the transmission line excites the antenna section which, in turn, excites the metal supporting pole and outside surface of the coaxial transmission line. The overall effect is that the whole antenna structure acts like a long antenna and consequently the vertical directivity is seriously distorted. By referring to Figure 17–78 it will be seen that, as the antenna exceeds a half-wave length, high-angle radiation takes place and the useful signal along the surface of the earth is diminished. Hence in the case of the emergency services operating on the very high frequencies it becomes imperative to take precautions to confine the radiated power to the antenna only so that the maximum signal will be radiated at low angles close to the surface of the earth so as to provide the best local coverage.

To achieve this purpose the Bell Laboratories developed the coaxial antenna. The coaxial antenna (Figure 17–79), consists of a quarter-wave section at the top of the pole, isolated from it by means of an anti-resonant high impedance circuit which serves to reduce materially the coupling between the quarter-wave radiating portion of the antenna and the supporting pole and, consequently, high-angle radiations which contribute nothing to the service area.

The enclosed sheath of the transmission line acts in conjunction with the inner surface of the large surrounding tube to form a short-circuited quarter-wave concentric line. The characteristics of this shorted section of line cause an extremely high

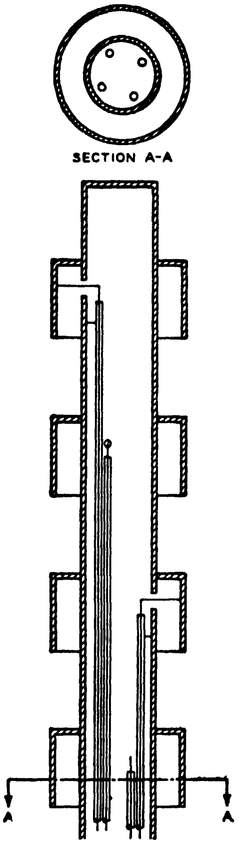


Fig. 17-80. Four-unit array of vertical dipoles.

impedance to be created across points A and B. This is equivalent to a high Q anti-resonant circuit which isolates the pole below point B from the antenna and reduces the stray pole current to a minimum and hence undesirable radiations.

When power is applied to this antenna, the center of the antenna is at minimum potential, the top is at a high potential and the bottom of the tube is at a high potential. The presence of the high Q anti-resonant circuit element at the bottom of the tube allows this high potential to exist even in the immediate proximity of the transmission line.

The concentric line which feeds the antenna is a standard ⅞-inch diameter gas-tight line and is placed for mechanical strength inside a heavy brass supporting pipe approximately 2 inches in diameter, both terminating in a solid brass bushing at the feed point, i.e., center of the antenna. A 3-inch diameter coaxial tube is attached solidly to this bushing at the feed point and elsewhere is kept insulated from the 2-inch pipe by internal ring insulators. The quarter-wave rod projects through a sturdy insulator at the feed point and is connected at the feed point to the inner conductor of the transmission line.

Electrically, this coaxial antenna is a center-fed doublet and consequently closely matches the surge impedance of a standard ⅞-inch concentric line. The doublet or dipole antenna consists of the quarter-wave rod and the outer surface of the 3-inch tube, which is also one-quarter wave long, making a total active radiator length of one-half wave.

The coaxial antenna of this type, while generally series fed, can also be skirt-fed. This is done by passing the center conductor of the transmission line through the supporting tube of the antenna structure and connecting it at a point of proper impedance matching on the skirt of the antenna. The length of the skirt must be accurately computed to insure proper performance of a coaxial antenna. The skirt in connection with the quarter-wave radiation portion of the antenna provides the proper termination for the transmission line. As stated previously in this chapter, if the impedance of the antenna at its feed point is not equal to the characteristic or surge impedance of the transmission line, some of the radio-frequency current is not radiated but reflected down the transmission line from which it is radiated, thereby destroying the low-angle radiation desired by the antenna system. In practice it is possible to keep the standing wave ratio within a value of 1.1 with a series-fed coaxial antenna, provided the skirt is of the correct length. A slight increase or decrease of the skirt length has a marked effect on the standing wave ratio.

17-71. Colinear Coaxial Antennas—Figure 17-80 shows a four-element coaxial antenna array in which the coaxial elements are colinear. In this case a metal supporting pipe over two wave lengths has four quarter-wave lengths between the sleeves and with a quarter-wave length from the top of the top sleeve to the top of the pipe. The manner of feeding energy to this structure can be varied to meet particular conditions. In the form shown,

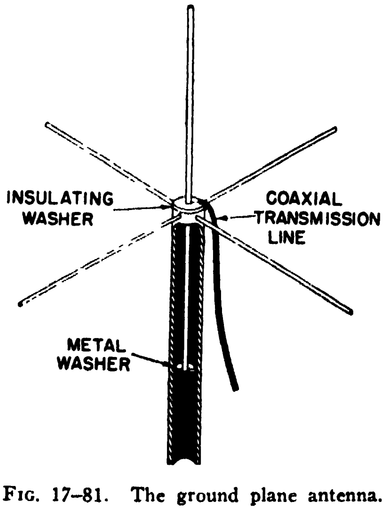


Fig. 17-81. The ground plane antenna.

four coaxial cables are carried up the inside of the pipe, and the central conductor of each coaxial line is connected to the inner surface of one of the sleeves through an opening in the pipe. The outer conductors of the coaxial lines are connected to the pipe opposite the sleeve to which their central conductors are connected. The exact location of the four points of connection is a matter of impedance matching and power transfer. The four coaxial cables are brought out near the bottom of the pipe and connected to the supply circuit from the transmitter. The phases at the points of attachment to the sleeves should all be alike, and this is brought about either by making all the coaxials of the same length or by other convenient means.

With such a coaxial structure, the full effect of multiple units with vertical polarization of the radiated wave is realized. There is a still further increase in radiated power, however, because the four units form a continuous structure. With a single, isolated antenna, the current at the ends is zero because of the infinite impedance at these points. When an array of antennas is continuous, however, the impedance at the ends of each unit is not infinite, and some current exists over the entire length of the array except at the top of the top unit and the bottom of the bottom unit. With the array shown in Figure 17–80, therefore, there is an additional useful power gain because of these conditions.

To attain the full advantage of such stacked arrays in practice, just as in the case of any antenna, their site must be carefully selected and should preferably be at a point well elevated above the surrounding terrain.

17–72. The Ground Plane Antenna—The ground plane antenna depicted in Figure 17–81 is designed to produce a low vertical angle of radiation and at the same time permits proper termination of the transmission line and placing the antenna structure at ground potential which provides protection from lightning.

Basically, the antenna is so designed that a parallel circuit is formed, whose impedance can be made to match the characteristic surge impedance of commercially available concentric transmission lines.

The four arms extending out from the top end of the outer sleeve of the concentric base support are ground radials and are necessary to lower the radiation resistance and decrease the effect of high-angle interference radiation originating on the supporting structure of coaxial feed line, the effects of which have been discussed previously.

Referring to Figure 17–81 it will be observed that the outer conductor of the coaxial transmission line is connected to the outer conductor of the base support at the point where the inner conductor is connected to the vertical or driven element of the antenna. The quarter-wave horizontal elements may be bolted directly to the supporting pole or mast. Since the inner conductor is connected to the outer conductor by a metallic shorting disc at its base the whole structure may be placed at ground potential, thereby providing lightning protection.

The use of the ground plane antenna is not limited to the very high frequencies, but can be used to advantage to secure low-angle radiation at high frequencies if space permits.

CHAPTER 18

RADIO EQUIPMENT FOR THE EMERGENCY SERVICES

This chapter describes transmitters and receivers employed in the Emergency Services licensed by the F.C.C. These services include state and municipal police systems, forestry, fire departments, railroads, and other public utilities. Space does not permit describing the many special applications of radio in the Emergency Services such as unattended transmitters that automatically operate to report the height of rivers and dams and other such special uses.

In the police and forestry service, acute problems have been encountered in many cases in the attempt to provide state wide coverage at all times. These problems have been overcome by a judicious choice of transmission and reception methods, locations, and directive antennae.

Amplitude modulation is widely used on the lower frequencies for fixed station equipment and on the higher frequencies for services wherein distances and noise levels are not a serious factor. It has been demonstrated that frequency modulation has definite advantages when distance and noise level become a factor. The low ratio of desired-signal-to-undesired-signal to overcome interference and the "capture effect" characteristics of F–M permit several stations to operate at one time with a minimum of interference.

F–M receivers have been developed for the Emergency Services that give limiter saturation and a 20-db noise reduction with an input signal of one-fourth of one microvolt, and with a squelch action that is positive on signals as low as one-tenth of one microvolt.

Advantage is also taken of the prevailing noise level to provide a control voltage of the squelch circuit to keep it closed except during reception of a carrier. The controlling voltage is used in series with a voltage derived from the current rectified in the grid circuit of the first limiter. If the noise level increases, the voltage developed both by the current through the limiter and the squelch circuit operates to keep the squelch closed. However, the voltage developed by a carrier will increase the squelch opening voltage and decrease the closing voltage so that the total voltage operating the squelch is the sum of the two changes in voltage thereby accomplishing unusual sensitivity and discrimination against noise. An ordinary squelch system opens on bursts of static and other sources of interference, and in some installations, the squelch may be adjusted to open on a weak signal but the proper discrimination against noise is not available.

The use of high frequencies for emergency service permits the use of directive antenna systems as well as unattended relay stations. The problem of state wide coverage encountered by the state of California is not unlike that encountered by other states, but it is of interest because of the unusual topographical situation having extremes in elevation and main highways extended between mountain ranges. It is for this reason that a description is included later in this chapter of the directive antennae and relay stations that are used to advantage in that state by the Highway Patrol. In addition, technical descriptions are provided in this chapter of fixed, mobile and relay F–M transmitters and receivers that are in common use in the Emergency Services.

18–1. Motorola Model FMT-30D F–M Radio Transmitter [1]—This 30-watt transmitter has been designed for mobile communications work in the frequency range from 30 to 40 mc and is adjusted for operation at a specified frequency in that range. If at any time it is desired to change the operating frequency, it is necessary to install a new crystal and retune the transmitter in accordance with instructions given below. This transmitter is furnished with a crystal which permits slight adjustments of operating frequency in order that all units of a system may be set to precisely the same frequency.

18–1a. Description—A complete installation includes the following equipment, (*a*) transmitter, (*b*) antenna, (*c*) control head, (*d*) microphone, (*e*) connecting cables, (*f*) installation and service manual, and (*g*) accessory kit.

To simplify the installation procedure, all units have been assembled as completely as possible, leaving a minimum number of operations for the installation man. Therefore, the actual installation in the car does not require unusual skill or knowledge, but can be accomplished by any good mechanic who will follow carefully the instructions contained in this book. Although any good mechanic can make the installation it is illegal for anyone to place this transmitter on the air and to tune or adjust it, except under the direct supervision of a qualified radio operator holding a radio telephone second class license or higher. (See section 13.630 F.C.C. Rules and Regulations.)

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[1] Galvin Manufacturing Co., Chicago, Illinois.

18–1b. Output Stage Alignment and Antenna Loading Procedure—An Ohmite D–100 34-ohm dummy antenna, together with an 0–1 amp r-f ammeter, or a 32-volt 25-watt (farm) lamp is required. Connect the load by very short heavy leads (2 inches or less) to a suitable connector and plug into antenna receptacle on the chassis control panel.

It is also imperative to have a 2000-ohm d-c resistance microammeter with 0 to 50 microampere range, and connecting cable and plug. This meter plugs into the meter jack on the chassis control panel and measures effective plate and grid currents.

With the housing off the transmitter and the plate power turned on, high voltages are exposed. Be very careful not to touch the tube plate cap, tuning condensers, or tank coil. It is wise to be cautious when working on any high voltage equipment. These voltages are dangerous. *Be careful.*

Pre-set the antenna tank condenser C29 to full mesh. Turn the filaments ON and allow them to heat up for at least 30 seconds before turning on plate voltage. Plate voltage is turned on by pressing the "push to talk" button on the microphone. Do not leave the plate voltage on more than a few seconds at a time until the power amplifier is properly tuned.

Tune the plate condenser C28 to resonance. This is indicated by a dip in plate current as indicated on the microammeter, when the meter switch is in the PA position. Load the power amplifier stage by decreasing the antenna tank capacitance (C29). With each decrease in C29, it will be necessary to retune the plate tank condenser C28 for minimum dip in the plate current as indicated on the microammeter.

The above process should be continued until the minimum dip (when plate tank condenser C28 is resonated) reads 27 on the microammeter.[2] This value represents a power amplifier tube loading of 100 ma. The r-f ammeter will indicate about 0.94 amp. If a 32-volt 25-watt lamp is used, it should light brilliantly. At the correct output stage loading, 100-ma plate current, the plate tank condenser should be somewhat in mesh.

Remove the dummy antenna and connect the transmitter to the antenna proper. Make sure that the preliminary adjustment of the antenna, as previously indicated, has been carried out. If, with the antenna tank condenser C29 completely in mesh, the output tube loading is greater than 27, this indicates that the antenna is not correctly matched. In order to correct this, two steps may be taken:

1. Change the antenna length until the tube can be loaded down to 27 by re-resonating the plate tank condenser.
2. Increase tank coil inductance. This is not desirable, but may be tried, if step No. 1 fails to produce the desired result or is not practicable.

It is desirable that the antenna tank condenser C29 be somewhat out of mesh when the power amplifier stage is correctly loaded in order to have plus or minus capacitance left for finer adjustment.

In some cars, because of their shape or position of the antenna, the location of the plate tank condenser C28 may not coincide with that obtained when using the dummy antenna. In some extreme cases, it will be found impossible to load the output stage to the correct value at the extreme low frequency end of the band, because of capacitive effects due to the antenna position, car shape, or antenna length. This may occur even though the antenna tank condenser is completely in mesh. A loading coil of about ¾ turn, 1 to 3 inches in diameter added at the base of the antenna, just inside the car trunk, and connected in series with the antenna and lead-in, will often make possible the correct loading of the output stage. This loop should be made of heavy self-supporting wire (no. 10 or heavier).

It is desirable to check the output frequency with a wavemeter at this point to make sure that the equipment is operating on the correct frequency.

18–1c. Importance of Wavemeter—It is important that a wavemeter be used, for without it there is a possibility that the various circuits may be aligned to the wrong harmonic of the oscillator frequency.

Because it is not practical to use a crystal ground to oscillate at ultra-high frequencies, the oscillator circuit operates at a lower frequency, which is only 1/32 of the transmitter frequency. To state the above in another way, a transmitter designed to operate on 32 mc has a crystal ground to oscillate at 1.0 mc. Therefore, when the transmitter, is tuned, the oscillator circuit will be resonated at a frequency near 1.0 mc. However, the other circuits (quadruplers and power amplifier) will be resonated not to the 1.0-mc fundamental frequency of the oscillator circuit but, instead, to its fourth harmonic for the 1st quadrupler plate tank, to the 16th harmonic for the 2nd quadrupler plate tank, and the 32nd harmonic for the driver plate tank and 32nd harmonic for the power output stage.

To double check and insure operation on the assigned frequency, it is suggested that a wavemeter be included in the station equipment. To use it, merely couple it to the tank coil of the power amplifier and adjust the wavemeter control until the indicator shows maximum deflection. The fre-

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[2] To compensate for differences in microammeters, the maximum power amplifier (PA) loading of this transmitter should be as follows: When using the Motorola K–8100 Microammeter Kit (Simpson No. 284 0–50 d-c microammeter with connecting leads and plug) load the power amplifier stage as indicated above, i.e., 27. All equipment (except those units used as exciters) using the 3″ Simpson 50 microampere panel mounting meter should have the power amplifier stage loaded to a point where the panel meter reads approximately 21 instead of 27 as indicated above. These conditions must be observed if maximum tube life is expected.

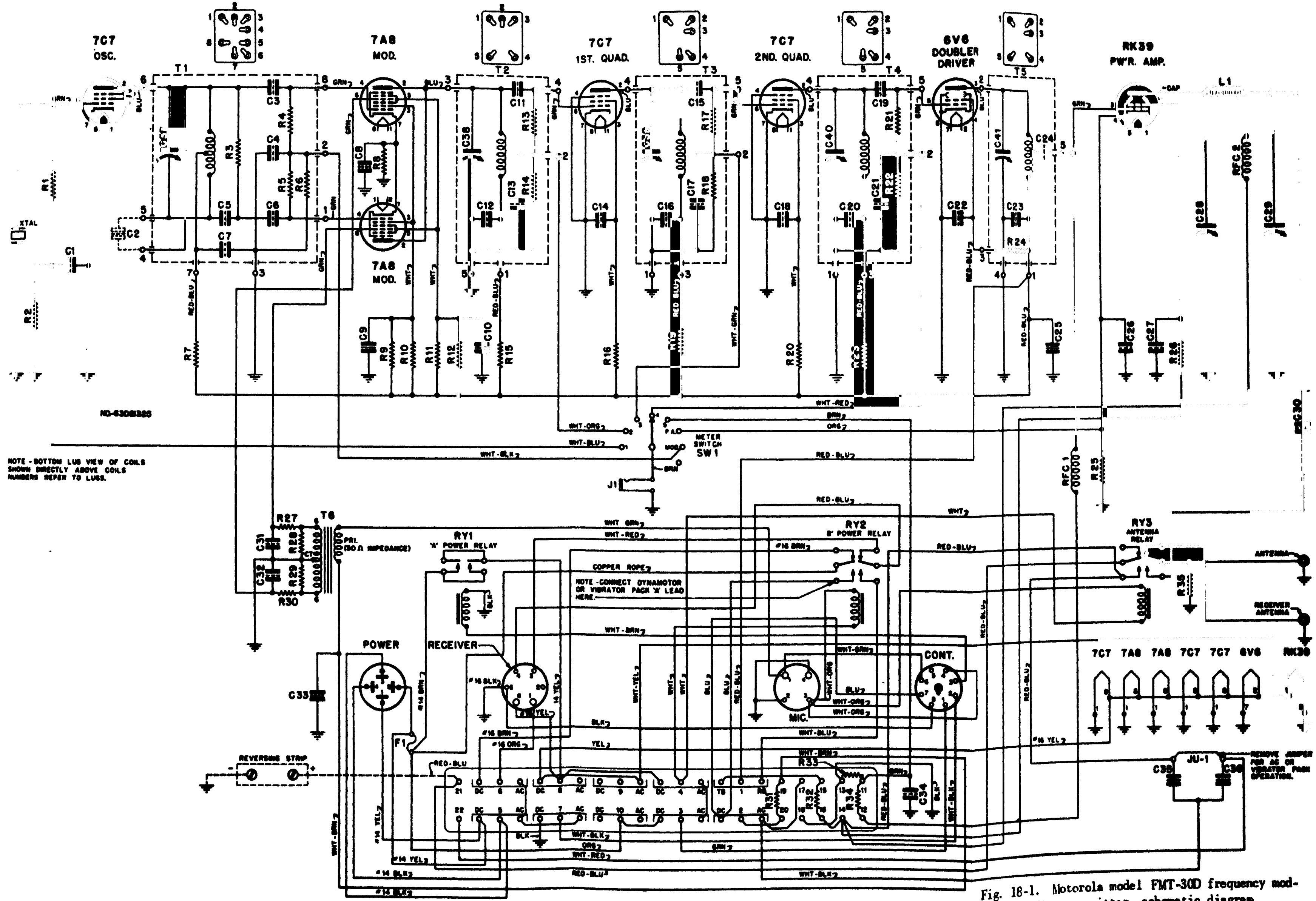

Fig. 18-1. Motorola model FMT-30D frequency modulated radio transmitter, schematic diagram.

quency of the transmitter will be indicated on the wavemeter dial.

18–1d. Operation—Turn the filaments ON by turning VOLUME CONTROL knob to the right at the control head. The pilot light behind the green jewel will indicate that the transmitter filaments are supplied with current. About one-half minute should be allowed for the tubes to warm up to operating temperature before attempting to place the transmitter on the air. Current consumption for filaments is 2.8 amp. Plate voltage is applied only when the transmitter is on; it is controlled by the press-to-talk button on the microphone, and is indicated by the red pilot light.

Press the TALK button. This button is located on the microphone and, when pressed, automatically connects the plate voltage, placing the transmitter "on the air."

Before pressing TALK button to apply plate voltage, be sure that the transmitter has previously been correctly tuned and loaded to the antenna. If the transmitter has not been correctly tuned, do not apply plate voltage until alignment instructions have been followed. Maximum current consumption when "on the air" is 30 amp.

The microphone should be held close to the mouth at an angle of about 45°; the operator should press the TALK button and speak clearly and distinctly so as to prevent car and extraneous noises from interfering with the desired message transmission. Speaking in a low tone or at low intensity should be avoided when the station to be called is in a noisy location because full modulation is required in order to get best noise suppression capabilities of frequency modulation.

18–1e. Tuning Adjustments—The transmitter was tuned and adjusted for its exact operating frequency at the factory. Unless it has been handled roughly while in transit, or otherwise abused or tampered with, it should require no further adjustment before placing it in service, other than to align the output amplifier stage to the antenna as has already been described.

If, for any reason, it becomes necessary for the transmitter to be returned, the following instructions outline the correct procedure.

18–1f. Alignment—This section includes alignment procedure for transmitter units using either iron-core or air-trimmer tuned coils. Be careful throughout the tuning procedure not to touch coils, condensers or other chassis parts. Some of them are hot with high voltage when the transmitter is on.

A rotary switch is located on the front of the transmitter chassis for the purpose of switching the alignment indicating meter into the various circuits. The meter plugs into a jack on the front of the transmitter chassis. The switch positions are numbered to correspond with the transformer coils. Number 1 position on the meter switch indicates the meter is in the circuit for tuning transformer T1, etc. The position marked MOD is not necessary in the tuning procedure. It is merely a check on the modulator circuit.

The center pin on the meter plug should be connected to the negative meter terminal to obtain a correct reading on all switch positions except the PA position. The meter leads must be reversed when the meter switch is in this position to get an upward deflection on the meter. Remove the plate cap from the top of the amplifier tube before proceeding to tune up the transformer coils. Never have the transmitter plate voltage on for more than a few seconds at a time until the transmitter is completely tuned. The plate current is high in untuned circuits and may result in damage to tubes and parts if the transmitter is left on for too long a period.

All air trimmers in the transformer cans increase capacitance by tuning clockwise. This decreases the frequency. All iron-core tuned coils increase inductance when turned into the transformer cans (clockwise rotation of screw). This decreases the frequency. The transmitter has been tuned to a requested operating frequency at the factory. Air-trimmer tuned coils have a red dot marked on the trimmer shaft and transformer can to mark the setting made at the factory. The frequency to which iron-core tuned coils are set can be determined approximately by the amount of the screw that is exposed above the transformer can. At 42 mc about 1⅛ inch of screw will be exposed; at 36 mc about ⅝ inch; and at 30 mc about ⅛ inch.

If for some reason it becomes necessary to change the frequency of the transmitter, the following must be observed when air-trimmer tuned coils are used in the transmitter. When the transmitter is to be operated between 30 and 33 mc, it is necessary to add a condenser (C2) across the air trimmer condenser (C37) in transformer T1. Refer to the schematic diagram. C2 is soldered to terminals No. 4 and 5 on the bottom terminal insulator of transformer coil T1. The value of C2 should be 25 $\mu\mu$f. When the transmitter operates above 33 mc, no condenser (C2) is used. When iron-core tuned coils are used, transformer coil T1 can be adjusted to any frequency within the frequency range of the transmitter unit without the addition of an extra condenser.

In addition to the regular microphone receptacle on the control head, another microphone receptacle is incorporated in the transmitter unit on the front of the transmitter chassis. This enables the operator or service man to use the microphone while working at the transmitter.

Using a nonmetallic screwdriver, tune each transformer coil T1, T2, T3, T4, and T5, respectively, for maximum indication on the meter. Make certain the meter switch is set to the correct position when tuning each coil. Each transformer coil will tune to several harmonics. Make certain each coil is peaked at the harmonic giving the greatest indication on the meter. It is desirable to tune T1 (crystal oscillator plate tank) a small amount to the high-frequency side of the resonant point (counterclockwise) for better oscillator stability and starting.

Before tuning the final amplifier, connect a 34-ohm Ohmite No. D–100 dummy antenna in series with an 0–1 amp r-f meter to the antenna plug. A 25-watt, 32-volt light bulb may be used instead for a dummy antenna. Total lead length should be less than 2 inches.

Before applying plate voltage to the final amplifier, set the bottom antenna tank condenser C29 to maximum capacitance (plate completely meshed). Set the top plate tank condenser C28 about ¾ open. Replace the plate cap on the final amplifier tube. Apply plate voltage momentarily and tune plate output tank condenser C28 for minimum reading on the meter with the meter switch set at PA.

The final amplifier should load to approximately 100 ma. To obtain this reading, decrease or increase the capacitance of the antenna condenser C29 and again retune plate condenser C28 for minimum dip on the meter. Repeat this procedure until the correct meter reading of 100 ma is obtained. The output indication on the r-f meter should then indicate approximately 30 watts output. When using a 25-watt light bulb, this should light the bulb quite brilliantly. Any change in the antenna condenser C29 requires readjustment of plate condenser C28 to bring the circuits back in resonance.

After the power amplifier has been tuned, the transformer coils should be readjusted to insure greatest efficiency.

When antenna loading is correct, approximate meter readings will be as follows, if Microammeter Kit K8100 or an equivalent 0–50 microampere meter with 2000 ohms d-c resistance is used.

T1	20	T5	25
T2	20	PA	21
T3	25	MOD	20
T4	12		

Any change in the value of the load resistance requires a readjustment of the antenna and plate condensers C28 and C29; therefore, when connecting the antenna in place of the dummy, the antenna circuit may no longer be in resonance and must be returned to match the antenna. The same procedure is used for tuning the antenna circuit as was originally used for tuning the antenna dummy. Regardless of the value of the load resistance, the transmitter will deliver the same output for a given value of plate current.

Check the frequency of the transmitter to make certain it is operating on the assigned frequency.

If the above instructions have been carefully followed, no trouble should be experienced with improper modulation.

For operation on the high-frequency end of the band, a six-turn antenna tank coil is used. For the low end of the band an eleven-turn coil is used. Check the tank coil to make certain the correct number of turns is used for the desired frequency.

18–1g. Miscellaneous Information

1. *Reversing strip.* A polarity reversing strip is provided underneath the chassis. The transmitter units are shipped from the factory wired for operation in cars with the negative side of the battery grounded, and it will be necessary to reverse the dynamotor leads on the reversing strip, if cars with positive battery ground are used.

2. *Substitute meters.* If a 50-microampere, 2000-ohm meter is not available, it is possible to use a 150-ma meter for aligning and loading the antenna and output stage. This meter should be connected in series with the 807/RK39 cathode resistor (R25). Any low-range microammeter may be used for emergency alignment of the low power stages.

3. *Receiver muting circuit.* One set of contacts on relay RY2 are used to mute the receiver in transmitter-receiver combinations. These contacts are wired to lugs 3 and 4 on the receiver receptacle, located on the transmitter front panel. If the receiver used in combination with this transmitter is a Motorola model FMR–13, muting during transmission is accomplished by bringing the receiver plate supply through the power interconnector cable to the relay contacts in the transmitter. In the transmit position, receiver plate power is opened, thus effectively muting the receiver. This same method of muting can be applied to any other type of receiver that may be used in combination with this transmitter. Other muting circuits may be devised using these control receptacle lugs.

4. *Dynamotor maintenance.* Dynamotor brushes should be checked for wear every few months. Brushes worn down to ⅜ inch should be replaced. The low-voltage primary brushes will wear faster than the secondary output brushes. Care should be exercised when inspecting or replacing brushes to make sure that brushes are placed in exactly the same position they occupied before removal in order to minimize commutator wear.

In some cases a ridge may be worn on the side of the secondary output brushes before their length wears down to ⅜ inch. This may cause these brushes to stick in their holder and cause considerable arcing. In this case, new brushes should be installed before they wear down to ⅜ inch.

5. *Battery connections.* Battery connections should be periodically inspected to see that they are clean and tight in order to prevent unsatisfactory operation of the transmitter due to low voltages caused by excessive voltage drop across loose connections. Also check the transmitter fuse to see that it is screwed snugly in its holder. Due to the

high current, it is imperative that the fuse fit snugly in its holder to prevent voltage loss at this point.

6. *Method of checking battery and cable connections.* Measure the voltage between pins 2 and 7 at the control head when the transmitter is operating (plate voltage on). For satisfactory operation, the voltage at this point should be at least 5.7 volts.

7. *Car generator.* The car generator should have an adequate output in order to keep the battery in good condition. Check generator connections periodically.

8. *Using receiver plate voltage for low-power stages of transmitter.* It is possible to increase the output of this transmitter slightly when the transmitter is used in combination with a receiver that is muted by opening its plate supply circuit The receiver power supply must be capable of supplying between 250 and 270 volts at 60 ma This is accomplished by connecting a jumper on the transmitter terminal board between RB and 1 This connects the receiver plate supply to the low voltage transmitter stages when the relay RY2 is in the transmit position.

18-2. Motorola Model FMT-25V F-M Radio Transmitter—This transmitter is approximately the same as model FMT-30D except that a vibrator power supply is used instead of a dynamotor, a filter choke is used, no polarity reversing strip is required, and the power output is 25 watts The r-f chassis and alignment are identical to the FMT-30D.

The vibrator power supply is a dual series connected unit using two vibrators and two gaseous rectifiers This supply does not have as high an output as the dynamotor The output for 5 6 volts input is approximately 540 volts at 150 ma, and due to this lower supply the transmitter output is reduced to 25 watts. Each of the two series connected supplies is separately fused in addition to the main fuse supplied in the r-f chassis proper. The vibrator power supply schematic diagram is shown in Figure 18-2

By connecting a jumper on the transmitter terminal strip, an external plate power source of 250–270 volts and 60 ma can be used to operate the oscillator, multipliers, and doubler driver stages Thus more voltage will be supplied to the output stage and give approximately five additional watts When used with the Motorola FMR-13V receiver, the cable interconnector automatically takes care of this.

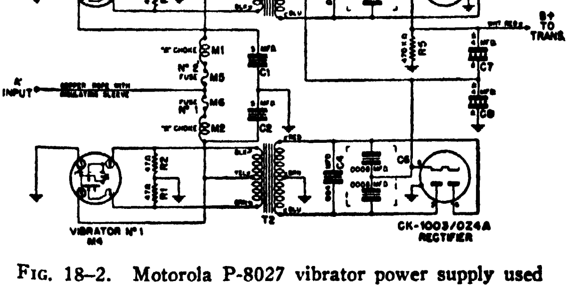

Fig. 18-2. Motorola P-8027 vibrator power supply used with FMT-25V transmitter

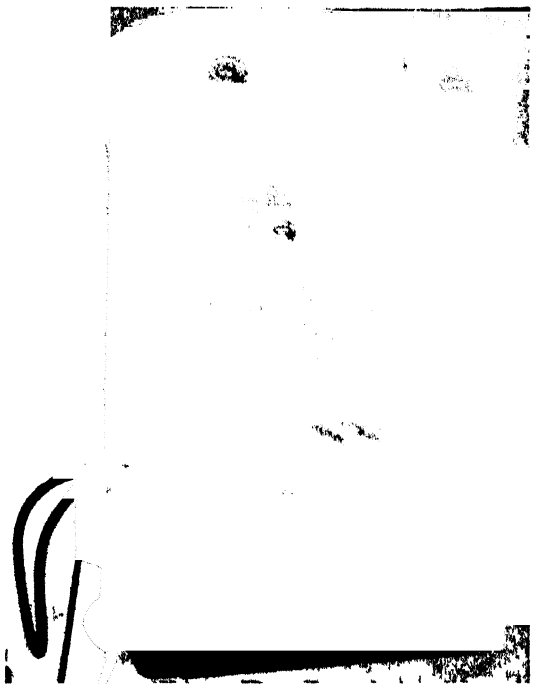

Fig. 18-3 Link radio transmitter-receiver type 50 UFS, open front view

The power supply is wired for two types of vibrators, those that have a separate set of points for actuating the deflecting coil and those that do not have the separate set of points

18-3. Link Radio Transmitter-receiver Type 50-UFS[8]—The Link radio transmitter-receiver type 50-UFS ed. 7 is a complete assembly designed for two-way communication in the 30-44 mc very-high-frequency band It consists of the 50-watt radio transmitter type 50-UFS ed. 7, radio receiver type 12-UF ed 6A and all accessories for accomplishing an operating two-way communication system in a fixed station. The equipment is designed to derive all of its primary energy from 115-volt 50-60 cycle a-c lines.

The transmitter, power supply, and receiver chassis are mounted with all the co-ordinating accessories in a completely enclosed rack cabinet. Front and rear doors give immediate access to any adjustments or circuit components for servicing. At the top front of the cabinet are located two meters reading PA plate voltage and current, filament and plate switches, pilot lamps, and the loud-speaker grill.

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[8] Link Radio Corporation, New York, N. Y.

Inside the cabinet, in addition to the chassis already mentioned, is a control and termination chassis containing the necessary circuits to provide for local and/or two-wire or four-wire remote control of the complete equipment. Terminals are also provided on this panel for local control wires, remote control pairs, and repeater control.

The remote control feature provides receiver-transmitter and control facilities over either one or two telephone pairs when used with a Link radio remote control unit type 1890. At the same time complete use of the normal local control handset is retained.

Further characteristics appear below:

Overall cabinet size: 21 inches wide, 11 inches deep, 34¼ inches high.
Total weight: 142 pounds.
Supply voltage: 115 volts, 50–60 cps.
Total input power (including receiver): Standby: 130 watts. Transmitting: 275–300 watts.
Frequency range: 30–44 mc.
System audio response: ± 3 db 300–3000 cps.

Radio transmitter type 50–UFS ed. 7 is a 50-watt (nominal output) frequency-modulated unit designed for rack mounting. Its more salient characteristics may be listed as follows:

Power output: 50 watts (nominal).
Frequency deviation: ± 15 kc.
Power input: From 115 volt a-c source Standby: 65 watts. Transmitting: 210–235 watts.
Output impedance: Any—usually fed into 50 to 70 ohm concentric line.

Radio transmitter type 50–UFS ed. 7 utilizes the phase-shift method of obtaining the desired deviation. This permits both direct crystal control of the carrier frequency and a simple circuit design with no critical tuning adjustments. A carrier power of 50 watts is available under normal operating conditions. The transmitter is entirely self-contained except for filament and high-voltage plate supplies for the tubes. Eight tubes are included on the chassis, six of which are of the low-drain receiving type. The crystal frequency is multiplied 32 times in order to obtain the final operating frequency. All tuning adjustments are straightforward and small errors in making them will not affect the output frequency, quality, or modulation level in any way.

Radio receiver type 12–UF ed. 6A is a 12-tube, crystal-controlled, single-frequency, frequency-modulation, superheterodyne receiver. Some pertinent characteristics follow:

Frequency range: 30–44 mc.
Type of signal: Frequency modulated.
Frequency deviation: ± 15 kc.
Audio response: ± 3 db 300–3000 cps (system) (sharp cutoff filter attenuates frequencies above 3000 cps).
Power input: 65 watts from 115 volt 50–60 cps a-c source.
Output impedance: 500 ohms.
Control: Co-ordinated with 50–UFS control.

Radio receiver type 12–UF ed. 6A utilizes 12 tubes in a double-conversion superheterodyne circuit. Two quartz crystals are employed to insure stable receiving conditions under all variations of temperature and humidity. The double i-f system makes possible excellent bandpass characteristics with a very favorable image ratio.

Three tuning meter jacks are located on the receiver chassis. One is for measuring the grid current of the first limiter, thus indicating resonance in all the preceding stages. The second is for measuring the grid current of the second limiter and the third is to permit adjustment of the balance of the discriminator circuit. The two former require the use of a zero to one milliampere meter while the third requires a fifty or one hundred microampere meter, center-zero type preferred. A monitor jack across the 500-ohm output is located on the receiver chassis to permit aural monitoring of the receiver when the loudspeaker is remotely located.

18–3a. Circuit Description

1. *Radio Transmitter Type 50–UFS Ed. 7.* The 50–UFS ed. 7 transmitter is a frequency-modulated transmitter utilizing the phase-shift method of obtaining frequency deviations and as such exhibits considerably different characteristics than the usual amplitude-modulated units. Intelligence is conveyed in variations of the constant-amplitude carrier wave. The use of the phase-shift method of frequency modulation allows direct crystal control of the mean carrier frequency, a necessity in unattended equipment. It necessitates, however, considerable frequency multiplication after modulation to generate sufficient frequency deviation. A number of small, low drain tubes are used for this function, and a total frequency multiplication of 32 times is affected.

(*a*) *Oscillator-modulator.* The twin triode V1 (7F7) acts as both crystal oscillator and phase modulator. The first half of the tube operates as a resistance-coupled aperiodic oscillator circuit. The crystal, which is connected between grid and plate, operates on the 32nd sub-harmonic of the output frequency. Since the output frequency range is 30–44 mc, the crystal frequency will lie between 937.5 and 1375 kc.

The second half of the 7F7 acts as a phase modulator. The r-f output of the crystal oscillator is

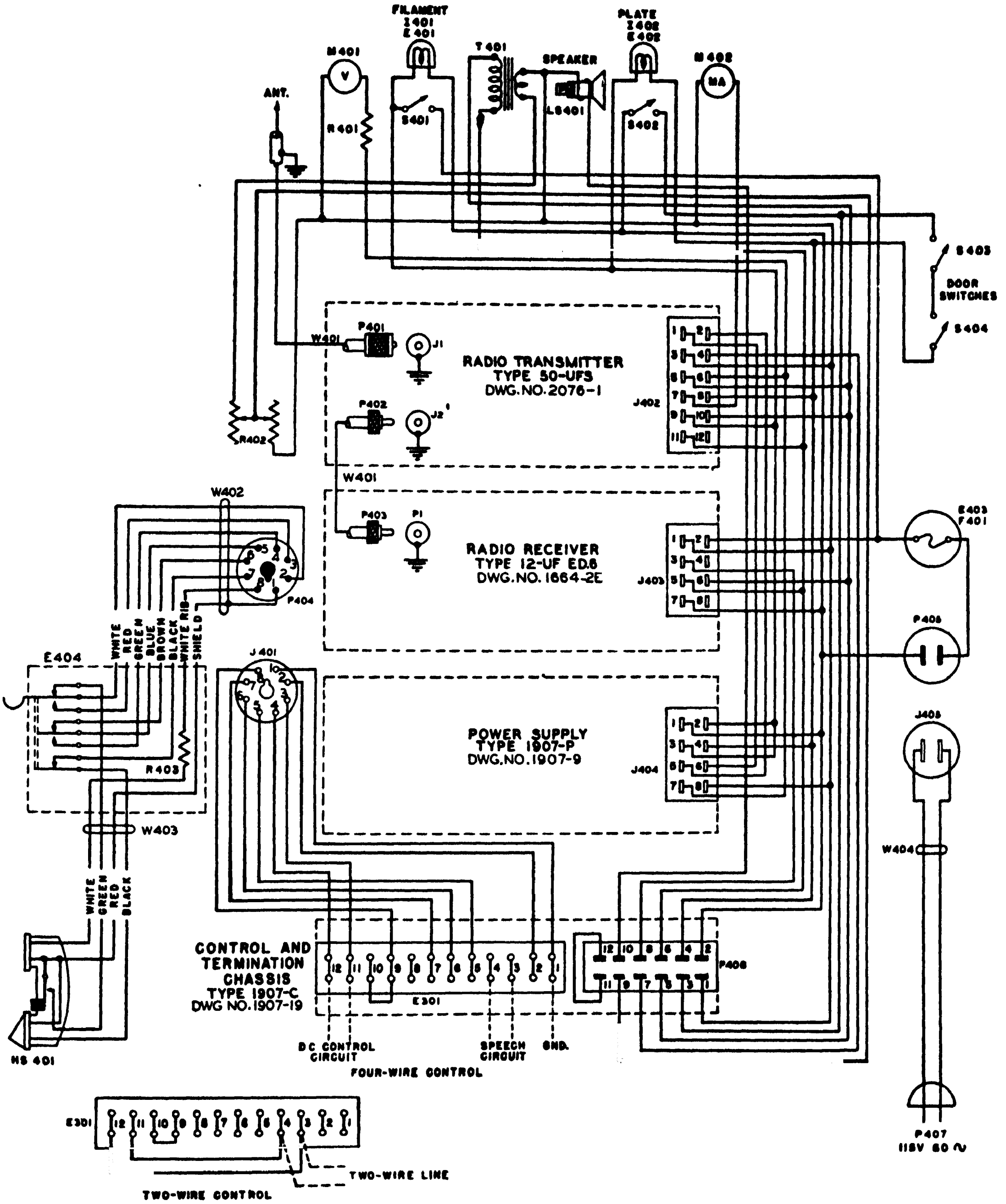


FIG. 18–4. Link radio transmitter-receiver type 50-UFS ed. 7, equipment assembly, schematic diagram.

impressed on the phase-modulator grid by means of the blocking condenser C4. The cathode circuit is provided with a large amount of degeneration by unbypassed resistor R3. Because of this degenerative feedback, the transconductance of the triode is abnormally low—so low that the plate current is affected about as much by the direct grid-plate capacitance as by the transconductance. The two effects result in plate current vectors almost 180° apart, and the total plate current is the resultant of the two components. In phase it will be about 90° removed from the phase of the voltage impressed on the grid.

When audio is impressed on the grid, thereby periodically changing the bias, and in consequence, the transconductance, the plate current, in both

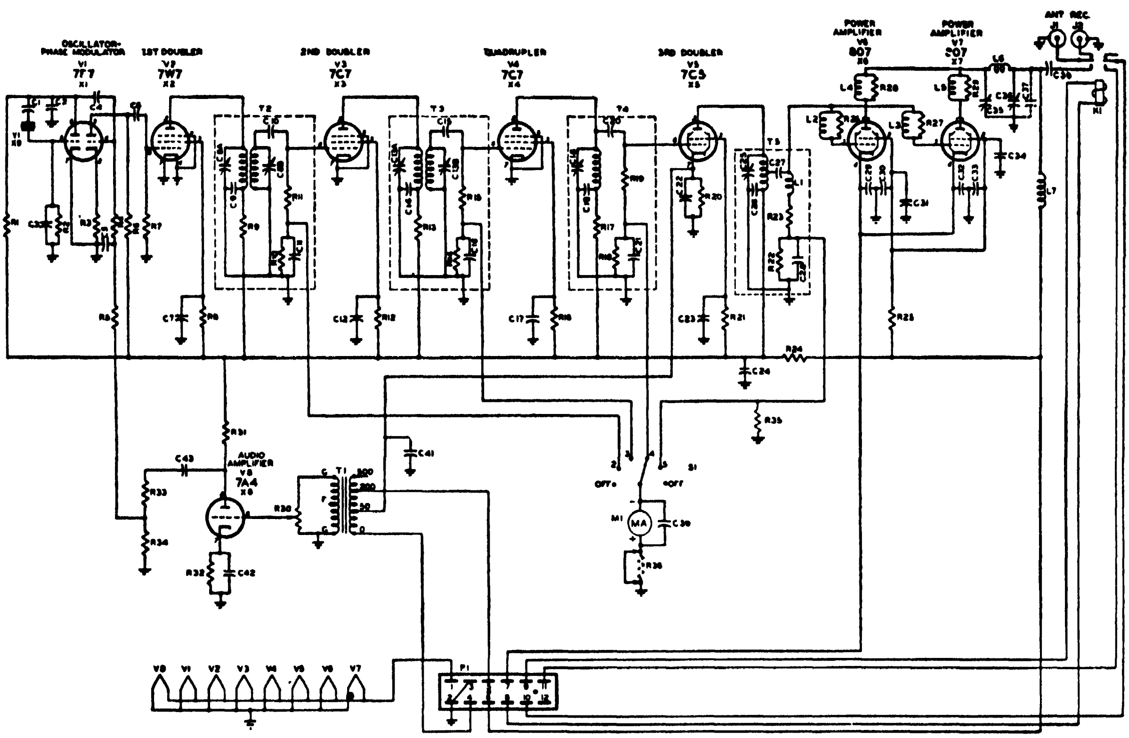


Fig. 18–5. Link radio transmitter type 50-UFS ed. 7, schematic diagram.

amplitude and *phase,* undergoes a periodic change. The amplitude modulation is unimportant, and is removed in the frequency multipliers which follow, but the phase modulation remains and is the essential element of the transmitted signal.

The phase modulation is modified by the use of a frequency-correcting circuit consisting of resistor R5 and condenser C5. These elements are connected between the phase modulator grid and audio amplifier V8. The frequency-correcting circuit is introduced because the frequency deviation brought about by phase modulation is linearly proportional to frequency, and pure phase modulation would become troublesome at high audio frequencies. The correcting circuit causes the deviation vs. frequency curve to begin to flatten out above 2000 cycles.

(*b*) *Frequency multipliers.* The frequency deviation which may be produced in a modulator such as described above is relatively small, usually not more than a value equal to the modulating frequency (otherwise severe distortion is encountered). To get sufficient deviation (± 15 kc) the frequency of the modulated wave must be multiplied considerably. (In this case it is multiplied by a factor of 32.) The multiplication is accomplished by a quadrupler and three doublers, which act as Class C radio frequency amplifiers with grid-leak bias. The grid drive in each case is well above saturation so that slight changes in tuning or reduction in tube emission can have little effect on succeeding stages. Up to this point, all stages use receiving type tubes working at relatively low plate and filament currents.

(*c*) *Power amplifier.* The power amplifier utilizes two 807 beam transmitting tubes (V6 and V7) in parallel as a Class C amplifier. Grid leak bias is used and, as in the preceding stages, the grid current is metered for alignment and testing. The plate tank and antenna circuit is of the Pi type for harmonic suppression and ease of adjustment. This circuit consists of plate tuning condensers C35, the tank coil L6, and the antenna loading condensers C36 and C37. The output is fed through blocking condenser C38 to antenna relay K1.

(*d*) *Audio amplifier and input circuits.* Audio input to the transmitter is derived either from a single-button carbon microphone or from a remote-control two-wire line. Input transformer T1 provides a 50 ohm or a balanced 200/500 ohm termination respectively for these two applications. Actually the transformer is terminated on one-half of the secondary in such a manner that the input impedance across the 0–200 terminals is approximately 500 ohms. Microphone current is derived from the cathode circuit of the third doubler V5 and is filtered by condenser C41.

The output of transformer T1 is amplified in the 7A4 audio amplifier, tube V8, and fed to the phase modulator from the voltage divider R33, R34. R30 is an adjustable gain control.

(*e*) *Control and power circuits.* Radio transmitter-receiver type 50–UFS ed. 7 has sufficient relay circuits for complete local or remote control and in addition is designed to provide all necessary relay and control functions for the radio receiver type 12–UF ed. 6A except applying the primary power which is done by the switch on the receiver volume control. The normal operating sequence is as follows:

Switch S401 on the cabinet applies primary voltage to the filament transformer on the power supply which in turns lights all filaments. The green pilot lamp on the front of the cabinet is lighted at the same time. In order to transmit, the receiver must be turned on to supply voltage for actuating the transmitter control relay K301.

A portion of the B voltage of the receiver is applied to the winding of relay K301 through the voltage divider R301–R302, R303, and handset push switch when the local handset is in use. When the local handset is not in use, voltage to actuate K301 is supplied by the two-wire/four-wire remote control unit.

When relay K301 on the control panel is energized, the two-wire line is transferred from the receiver output to the transmitter input, relay K1 on the transmitter chassis is energized and at the same time primary power is applied to the transmitter plate supply.

Relay K1 (transmitter chassis) shorts the receiver audio output, thus muting the receiver, and transfers the antenna from the receiver input to the transmitter output at the same time.

The twelve-terminal strip on control and termination chassis type 1907–C provides facilities for either two- or four-wire control connections.

2. *Radio Receiver Type 12–UF Ed. 6A.* While radio receiver type 12–UF ed. 6A is designed to receive signals wherein the intelligence is conveyed in the variations of carrier frequency about a mean frequency instead of variations in the amplitude of the carrier about a mean level as in amplitude modulation, there are only three fundamental differences between amplitude and frequency modulation receivers.

The first difference is in the bandpass characteristics. Since the carrier frequency varies over a band of plus and minus 15 kc about the mean carrier frequency, the receiver has to accept a band at least 30 kc wide. Thus the intermediate-frequency transformers are designed to pass a relatively wide band compared to an A–M receiver.

The second difference is that since only variations in frequency are to be converted into intelligence, amplitude variations of the signal must be removed. This function is accomplished by the limiters. They are, in effect, saturated amplifiers so that increasing the input to them above a certain level will cause no increase in their output. Thus they "limit" the magnitude of the signal applied to the discriminator to a constant level. The excellent signal-to-noise ratio of the 12–UF ed. 6A receiver is largely due to the use of two cascaded limiters. On signals too weak to effectively saturate the first limiter, the second limiter is already saturated and removes whatever amplitude noise variations the first limiter has permitted to pass.

The third difference is in the method of detection; that is, the conversion of frequency variations into audio frequencies. This function is accomplished by the discriminator transformer (T7) and the 7A6 detector. This device is similar in operation to certain types of automatic frequency control discriminators used in broadcast receivers.

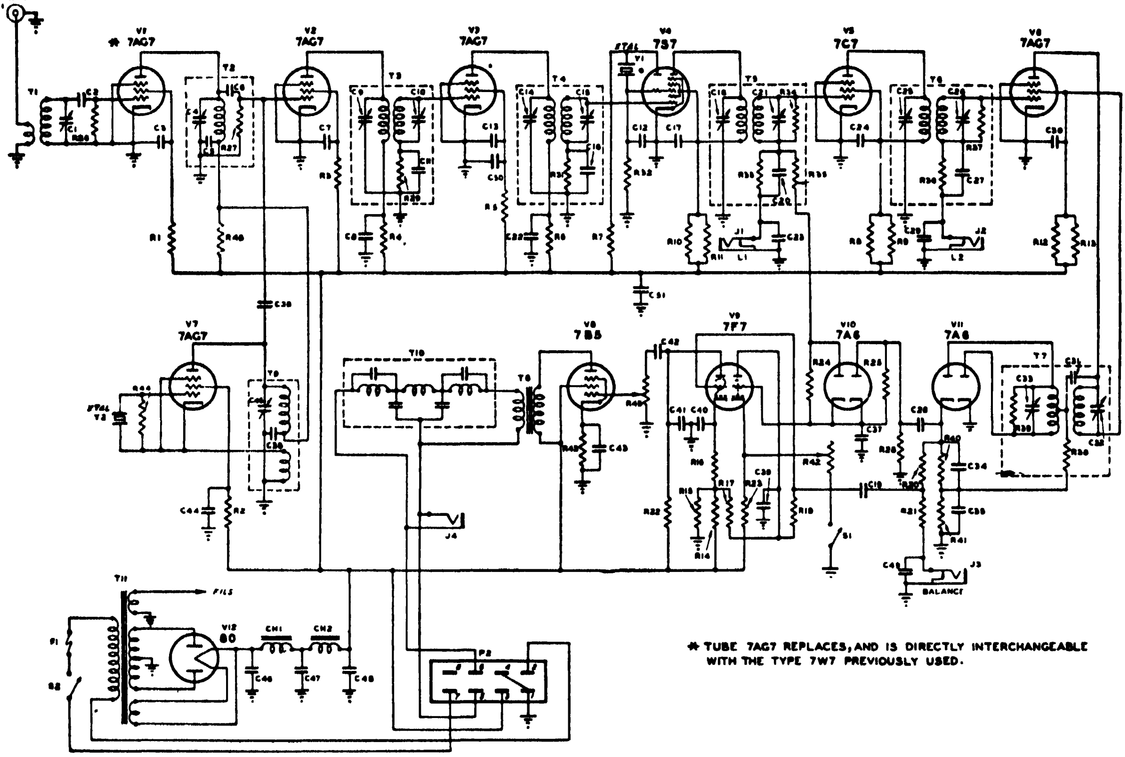
(*a*) *R-f amplification and mixing.* The antenna input circuit of radio receiver type 12–UF ed. 6A is designed to match a 50–70 ohm concentric line. A 7AG7 (V1) serves as a high gain r-f amplifier with both grid and plate circuits tuned for maximum efficiency. The output of the r-f amplifier is converted to the first intermediate frequency of 5000 kc in the 7AG7 mixer (V2) by beating against the output of the local oscillator.

(*b*) *Crystal oscillator.* The local oscillator is a crystal-controlled 7AG7 r-f pentode (V7). The tank circuit is tuned to the fourth or fifth harmonic of the crystal and a portion of the voltage appearing across it is injected into the mixer grid circuit to obtain the desired frequency conversion.

(*c*) *I-f Amplifier and converter.* One stage of amplification on 5000 kc is provided using a 7AG7 (V3) as the amplifier. Its output is applied in turn to the 7S7 converter (V4) where the frequency is changed to the final intermediate frequency of 456 kc. This is accomplished by using the oscillator portion of V4 as an aperiodic oscillator with a 5456-kc crystal connected between plate and grid. The crystal is of the same high quality as the signal frequency crystal.

The beat between the 5000-kc output of the first i-f stage and the 5456-kc crystal results in the final intermediate frequency of 456 kc which is amplified, passed through the i-f transformer T5, and applied to the grid of the 7C7 first limiter (V5).

(*d*) *Limiters.* The two following stages (V5 and V6) utilize 7C7 and 7AG7 tubes respectively as current limiting amplifiers, and the circuits and actions of the two stages are identical. The tubes are operated at low plate and screen voltage and without bias except that derived from the grid leak and condenser combination R33, C20, and R35, C27. These stages act as Class C amplifiers, giving no increase in output current or voltage once the impressed grid voltage has exceeded a threshold value of about 2 volts rms. Voltages above this value cause increasing rectification in the grid circuit, automatically setting up a bias to limit the peak plate current. Due to the low plate and screen grid voltages saturation occurs at a low level of grid voltage. The time constant of the grid leak and capacitor is chosen to be long compared to the 456-kc



* TUBE 7AG7 REPLACES, AND IS DIRECTLY INTERCHANGEABLE WITH THE TYPE 7W7 PREVIOUSLY USED.

Fig. 18–6. Link radio receiver type 12-UF ed. 6, schematic diagram.

intermediate frequency, but short enough to follow rapidly-fluctuating, high frequency noise peaks.

By cascading two such stages, the limiting effect of one tube is multiplied by the limiting effect of the other and essentially perfect limiting is obtained. Furthermore, by properly proportioning the circuit constants of the first limiter, the input to the second limiter grid is maintained at the optimum voltage for most effective action.

The grid return circuits of all the r-f and i-f tubes contain high resistances. By this means, blocking of any of the stages on strong signals is eliminated due to the bias developed across these resistors as soon as the associated grid draws current. A further advantage of this method is that as the incoming signal's strength is increased, the tubes ahead of the first limiter will also act as limiters as soon as their grids draw current.

Sufficient gain is incorporated in the receiver so that the smallest incoming signal which could be considered comparable with the noise generated in the grid circuit of the first tube causes saturation of the second limiter. The first limiter is in turn saturated by signals of 0.25 μv or over.

(*e*) *Discriminator.* The output of the second limiter, free of amplitude variations, is fed through discriminator transformer T7 to the 7A6 balanced detector (V11). The primary and secondary of the discriminator transformer are coupled both inductively and capacitively. Two voltages of different phase are thus applied to each half of the 7A6. The discriminator is so adjusted that when a steady carrier (456 kc) is received the voltage applied to the two halves of the 7A6 cause equal and opposite current to flow through the load resistors R40 and R41. Thus the resultant voltage appearing across the two resistors is zero.

If any frequency other than 456 kc appears at the discriminator the out-of-phase components of the 7A6 will be unbalanced and a positive or negative resultant voltage will appear across R40 and R41. The sign and magnitude of this voltage will follow the frequency of the impressed i-f voltage rather than amplitude changes in it. In this manner an audio voltage (varying in amplitude) is derived from the frequency variations of the incoming signals. The fact that the resultant d-c output voltage of the discriminator and detector should be zero when a carrier of the correct frequency is impressed, is useful to assist in tuning this transformer. A jack is connected through filter resistors R20 and R21 to the output of the 7A6 so that a sensitive microammeter (0–100 μa center-zero type preferred) may be plugged in and the necessary adjustments made for zero reading.

(*f*) *Squelch circuits and audio amplifier.* The audio-frequency output of the discriminator is passed through a voltage divider network consisting of resistors R20 and R21 where the output of the discriminator is reduced to prevent overloading of the 7F7 audio amplifier (V9). The audio frequency is then applied to grid G2 of V9. The first triode section of V9 is used to disable the second section when no carrier is received. The actuating voltages for the squelch circuit are obtained from two sources. One is rectified limiter grid current and is dependent on signal or noise level. The other is the high-frequency audio component at the output of the discriminator and is dependent only on signal-to-noise ratio.

The negative voltage generated by the passage of the first limiter grid current through R34 is applied to the first triode grid of V9 (7F7) through isolation resistors R35 and R24. The latter resistor is connected across diode V10 (7A6) which acts as a noise trap to eliminate the rectified audio noise present in the limiter grid circuit. An appropriate time constant in the squelch circuit is effected by condenser C37. The higher audio frequency components appearing at the discriminator output are selected by condenser C28 and rectified in the other half of the 7A6 squelch control diode (V10). A ground return is provided by resistors R25 and R28.

Under standby or no signal conditions a small negative voltage is applied to the squelch control circuit due to set noise being rectified in the first limiter grid circuit. At the same time the fluctuation noise present in the receiver causes a positive voltage to be generated and applied to the squelch control circuit as shown above. These two voltages tend to balance each other under any noise conditions, since an increase or decrease in fluctuation noise will cause like changes in both bucking components. The first triode grid of V9 is then normally slightly above ground potential. The corresponding cathode of V9 is also positive by virtue of the divider R23–R42, and R42 is adjusted to just render the squelch half conducting.

The cathode of the audio portion of V9 is also held positive by voltage divider R14, R15, but at a considerably higher potential than the squelch cathode. With the squelch portion conducting, a voltage drop will occur through R17, placing the grid at a sufficiently negative voltage with respect to its cathode to cause plate current cut-off and blocking of the audio output.

When a signal is received, more negative voltage is generated in the first limiter grid circuit and at the same time the noise quieting property of the F–M receiver causes less audio noise to be rectified and consequently a less positive voltage applied to the squelch control circuit. These changes are aiding in polarity and cause the potential on the grid of the squelch half of the V9 to go in the negative direction; thus the squelch half of the V9 will become non-conducting.

With no potential drop through R17 the audio grid assumes the potential existing at the junction of R14, R15 and R16, and the audio portion of V9 acts as a normal amplifier. The switch in the cathode circuit of the squelch triode is primarily intended to render the receiver operative during alignment and servicing.

Due to the design of the limiters, the squelch circuits and the audio amplifiers, an excellent degree of noise discrimination is obtained in radio receiver type 12–UF ed. 6A. The squelch may be set so that a signal of less than one-tenth microvolt will completely open the receiver while noise peaks of very high intensity will not be received.

The 7F7 audio amplifier is followed by a 7B5 output pentode (V8) with the volume control in the grid circuit of the output tube. The audio output from the 7B5 is passed through output transformer T8 and audio filter T10 to pins 5 and 6 on plug P2. T10 is an "M derived" filter with a 3000-cycle cut-off, so as to attenuate the higher audio frequencies. A monitoring jack (J4) is bridged across the 500-ohm line at this point.

18–3b. Tuning and Adjustment

1. *Radio Transmitter Type 50–UFS Ed. 7.* A meter and meter switch are integral parts of the transmitter and serve to measure the grid current of the various stages. The position numbers on the meter switch correspond with the numbers on the tops of the r-f transformers. Thus r-f transformer T2 is tuned for maximum current in the meter with the meter switch in position 2, etc. For initial tune up it can be assumed that all the circuits are in proper tune except the PA and ANTenna tuning adjustments. The transmitter may be energized for tuning or testing purposes from the switches on the unit, or from the local control handset. In either case the FILAMENT switch on the front of the 50–UFS cabinet must first be turned on. To permit adjustments to be made with the doors open, an INTERLOCK SHORT switch (S301) has been provided on control and termination chassis type 1907 C. Closing this switch short-circuits the protective door switches. Plate power may then be applied either by the PLATE switch on the front of the cabinet, or from the push-to-talk button on the local control handset, and tuning adjustments made. The protective function of the door switches should be restored when adjustments are completed by throwing the INTERLOCK SHORT switch OFF.

In order to tune the output circuit of the transmitter, disconnect the antenna cable from the transmitter chassis, place the antenna tuning condenser at maximum capacitance, and adjust the PA tuning condenser for minimum cathode current as read on the meter on the front of the cabinet. This current should be approximately 100 ma. Connect the antenna and resonate the PA tuning adjustment for minimum current. The loaded PA cathode current should be approximately 175 ma. If it is less than this value, decrease the ANTenna tuning capacitance in small increments, retuning the PA adjustment each time for minimum cathode current. Continue this process until the PA cathode current is 175 ma on the minimum adjustment of the PA tuning. Lock nuts are provided to maintain these adjustments.

(*a*) *Adjustment of transmitter audio gain.* The gain of the transmitter audio amplifier is controlled by potentiometer R30 and its proper adjustment requires the use of a receiver tuned to the same frequency as that of the transmitter. If the radio receiver type 12–UF ed. 6A in the equipment cabinet is not on the same frequency, it is possible to use a mobile or other receiver which is tuned to receive signals from the transmitter being adjusted.

Plug a test meter into the first limiter metering jack on the receiver. Place the transmitter in operation and note the first limiter grid current reading on the receiver test meter. This should be done with the transmitter audio gain control in the off (fully counterclockwise) position. While talking into the handset in a normal manner, slowly advance the setting of the audio gain control until modulation peaks cause the receiver first limiter grid current to swing downward not more than ten percent of the unmodulated reading. This is the correct setting.

(*b*) *Adjustment of receiver audio gain.* When local operation is employed, the speaker volume control should be rotated to the maximum volume position (fully clockwise). The gain control (R45) on the receiver chassis should then be advanced clockwise until a speaker volume level is reached that is the maximum desired. The receiver gain control should then be left in that position and the speaker volume controlled entirely by the gain control on the side of the cabinet. The maximum attainable volume will then be limited by the setting of the receiver gain control.

2. *Radio Receiver Type 12–UF Ed. 6A.* After the receiver has been completely tuned, the SQUELCH control may be adjusted. The most sensitive position of this control is completely clockwise. With the adjustment in this position and the SQUELCH switch ON, advance the volume control and observe the output of the receiver with no signal input. Turn the squelch adjustment in a counterclockwise direction until the output of the receiver is entirely silent. This adjustment will hold for most noise conditions, no matter how severe, as a result of the special circuits incorporated in the design of the 12–UF ed. 6A. Note that in its most sensitive position, the squelch sensitivity is better than one-tenth microvolt and that even this very sensitive adjustment may prove sufficient in many cases to silence the receiver between signals.

With the volume control advanced and the SQUELCH switch in the OFF position, a loud rushing noise should be heard in the loud-speaker even with the antenna disconnected. If the SQUELCH switch is placed in the ON position, all output from the loud-speaker should cease because of the action of the squelch circuit.

The loud noise present in the loud-speaker with the SQUELCH switch OFF is entirely normal and characteristic of an F–M receiver of adequate sensitivity. Any amount of noise introduced into the receiver or picked up by the antenna will not alter or intensify the characteristic sound of this noise unless a carrier is being received. In the latter case, even a weak signal will greatly reduce or completely suppress the noise.

18–3c. Operation

(*a*) *Normal procedure* (*local control*). Radio transmitter-receiver type 50–UFS ed. 7 in the standby condition has the FILAMENT switch on the front of the cabinet on, and the PLATE switch off. To transmit, lift the handset from the hang-up hook, press the push-to-talk button on the handset and talk into the mouthpiece. Immediately after talking release the push-to-talk button. The incoming signal will be audible in the handset receiver. At the end of the communication, replace the handset on the hang-up hook.

(*b*) *Emergency communication with control points.* When radio transmitter-receiver type 50–UFS ed. 7 is used with a remote control unit, it is possible to converse with the remote location for test or servicing, or during emergencies. The equipment is not designed specifically to perform this function, but in an emergency may be operated in the following manner.

After unlocking and opening the front door of the cabinet, plug a pair of headphones into the audio jack (J4) on the receiver chassis. Throw the INTERLOCK SHORT switch on control and termination chassis type 1907–C to the ON position. Pick up the handset, depress the push-to-talk button and talk. The speech will be transmitted on the air, but it will also be carried over the two-wire line to the remote control unit where it will be heard in the loud-speaker.

Speech originating in the normal manner at the remote control unit will be carried over the two-wire line to the transmitter where it will be heard in the headphones. This speech will not go on the air however, since control of the transmitter from the remote control unit is prevented when the handset at the transmitter is removed from the hang-up hook.

To return the equipment to normal operation, throw the INTERLOCK SHORT switch to the OFF position to restore the protective function of the cabinet door switches, unplug the headphones, close and lock the front cabinet door and replace the handset on the handset hang-up.

(*c*) *Operating technique.* Good operating technique is characterized by speaking distinctly in a normal voice and by keeping each transmission brief. If there are several instructions to be given, it is better to state them one at a time and have each acknowledged. Avoid long one-sided discussions. Before calling be sure the air is clear.

18–3d. Maintenance and Service

1. *Radio Transmitter Type 50–UFS Ed. 7.*

(*a*) *Maintenance.* Radio transmitter type 50–UFS ed. 7 is accurately adjusted at the factory for the specified operating frequency but the brief tuning procedure given in Section 18–3b should be followed on installation. For routine maintenance checks however, a more thorough check-up of transmitter performance is desirable to locate tubes that might be getting weak and should be replaced. As has been previously explained, a large factor of safety exists in the output of each stage of the transmitter so that no drop in power output will result from one or more tubes depreciating to a considerable extent. A routine check will, moreover, indicate these weak tubes before any loss in performance is noticed.

A meter and meter switch are located on the front of the transmitter chassis. They afford a complete check-up on the condition of the unit. The numbering of the meter switch and r-f transformers is so co-ordinated that the meter switch is placed in position 2 to tune transformer T2, etc. The meter reads the grid currents of the second doubler, quadrupler, third doubler, and PA respectively. The meter scale is 0–1 ma, and in position 5 of the metering switch it is shunted by a multiplier to read 10 ma. The P-A plate current is read on the meter on the front of the cabinet. It is used to adjust the P-A plate and antenna loading circuits as described in Section 18–3b.

All tuning adjustments except for the output circuit are made for maximum grid current in each successive stage, and the following table indicates typical readings. The values given are average at a line voltage of 115 volts. Higher or lower voltages will, of course, slightly alter readings.

Switch Position	*Transformer*	*Circuit*	*Current*
2	T2	7C7 2nd doubler grid	0.4 ma
3	T3	7C7 Quadrupler grid	0.3 ma
4	T4	7C5 3rd doubler grid	0.5 ma
5	T5	807 PA grids	*4–4.5 ma

* With a meter having a 0–1 ma scale this value is 0.4 to 0.45.

A substantial decrease below any of these values will indicate a weak tube, probably in the stage whose plate circuit is being tuned, and that tube should be replaced.

(*b*) *Service and test.* Maintenance of radio transmitter type 50–UFS ed. 7 will consist primarily of routine tube replacement when necessary. All components are operated under conditions which insure long life, and failures have proven rare in field service. Since every stage is metered, nearly all possible conditions will be reflected in the meter readings and servicing is reduced to simple deduction. Section (a) above has covered the routine tuning of the transmitter. By comparison with the table of currents given therein, or by comparison with values known from experience to be normal, trouble may be quickly isolated in a particular tube or stage.

(*c*) *Changing frequency.* In tuning radio transmitter type 50–UFS ed. 7, each transformer is tuned for maximum current in the like numbered meter switch position. In some cases, however, there may be more than one maximum current point in the tuning range of the capacitor, since the necessary range will permit the quadrupler to tune to other than the fourth harmonic. The transmitter tuning adjustments when made to the original frequency at the factory are marked with red lines so that no mistake can normally be made in making routine adjustments. When changing to a new frequency however, care should be taken to insure the proper selection of harmonics.

Transformer T4 will very often show two tuning points corresponding to the fourth and either the third or fifth harmonics. These may readily be separated by observing the position of the tuning condenser. All condensers have stops limiting their rotation to 180°. Maximum capacitance is fully clockwise. Since the tuning range corresponds to 30–44 mc, reference to the desired operating frequency will fix approximately the correct position of the condenser.

2. *Radio Receiver Type 12–UF Ed. 6A.*

(*a*) *Maintenance.* The receivers are carefully tuned at the factory to the specified operating frequency but should be retuned upon installation as indicated in Section 18–3b. Routine maintenance checks should include realignment of these same circuits. The correct settings of the transformers have been marked with red lines and these markings should be used as a guide when making any adjustments. It should be noted that for these adjustments the signal source must be accurately adjusted to the proper frequency. Signal generator calibration charts are not accurate enough for this purpose. The input signal should either be obtained by direct pickup from a crystal-controlled transmitter or from a signal generator which has been adjusted to zero beat against a crystal controlled transmitter on the correct frequency.

The frequency of the signal generator may be adjusted to that of a crystal controlled transmitter by use of the discriminator balance, as follows:

Plug a test meter into jack J3 on the front of the receiver chassis.

Apply a strong signal from a transmitter on the correct frequency.

Note the reading on the meter and, if it is not zero, readjust the secondary tuning (BAL.) condenser on the top of the transformer T7 with a nonmetallic screwdriver to obtain a zero reading on the meter.

Remove the source of signal from the receiver. The discriminator is now in exact adjustment, and may be used as a frequency indicator.

Apply a strong signal from the signal generator to the receiver antenna connector (P1) and note the reading on the "balance" meter. As the frequency of the signal generator is adjusted slightly above and below the proper operating frequency, the "balance" meter should swing sharply to opposite sides of the zero position. When the signal generator is adjusted in this manner for zero meter reading, its output is on the correct frequency.

The primary of the discriminator transformer (T7) is set at the factory and need never be readjusted. It will be found that this circuit is so band-spread and over-coupled, that there is no possible change in the tuning of the primary that cannot be compensated for by readjusting the secondary. When any of the tubes associated with the foregoing circuits are changed, those circuits should be retuned. The variations encountered in tubes may cause a marked detuning at very high frequencies.

If a signal generator whose output is calibrated in microvolts (or one whose output can be attenuated to a low level) is available, the sensitivity of the receiver can be checked. When the receivers are shipped from the factory their sensitivity is such that a signal of one microvolt or less, when applied to antenna connector P1, will cause a meter reading at jack J1 of at least 40 microamperes. If a signal generator whose output can be attenuated but which is not directly calibrated is available, it can be checked against a new receiver. The attenuator setting for some particular tuning meter reading can be noted and other receivers checked for sensitivity against this criterion.

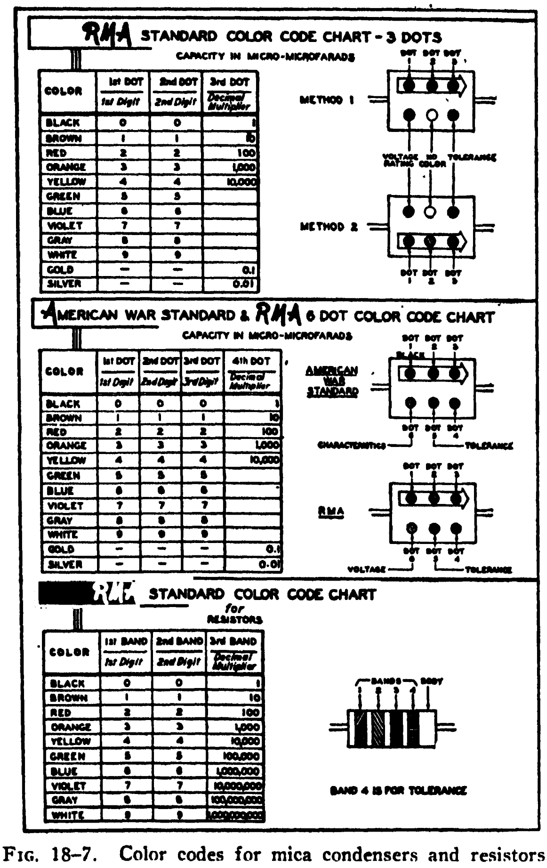
(*b*) *Service and test.* The following section is offered to assist the service engineer in quickly localizing and remedying failures that may arise during the operation of the receiver.

In setting up the receiver for operation on a frequency in 30 to 44 mc band other than that for which it was tuned at the factory, or if a complete realignment of the receiver is desired, a crystal of the right frequency for the new operating frequency is inserted into the crystal socket beside the 7AG7 oscillator tube (V7). The oscillator frequency is the difference between the signal and the 5000-kc intermediate frequency. The crystal is ground to one-quarter the oscillator frequency for signal frequencies below 37.5 mc, and to one-fifth the oscillator frequency for signal frequencies above 37.5 mc. The red lines on the transformer cans should be used as a guide to the approximate setting.

After the oscillator has been set roughly, r-f transformer T2 may be adjusted. While feeding a strong signal on the new signal frequency into the antenna, plug a tuning meter into jack J1 (marked L1) and tune T2 for maximum current. This transformer is marked with red lines in the same manner as the oscillator and the approximate setting can be arrived at in the same manner. The antenna transformer may next be adjusted for maximum current in the tuning meter. Once the approximate setting of the tuning controls is determined in this manner, the signal input is decreased until only a slight indication is obtained on the tuning meter and the adjustments on T1, T2, T3, T4, T5 and T9 set carefully for maximum current in the tuning meter.

The last i-f transformer (T6) is past the first limiter grid circuit and the tuning meter will give no indication of proper tuning in jack J1. To tune T6, plug the tuning meter into jack J2 (marked L2) and tune for maximum current. The discriminator transformer is next adjusted by plugging a center-zero microammeter into jack J3 (marked BALANCE) and adjusting the secondary of T7 for zero reading on the meter while receiving a strong signal. After the discriminator transformer has been balanced, the signal should be removed from the receiver and the balance meter reading noted.

If this reading is not zero the indication is that the bandpass characteristics are not accurately cen-


RMA STANDARD COLOR CODE CHART - 3 DOTS

CAPACITY IN MICRO-MICROFARADS

COLOR	1st DOT 1st Digit	2nd DOT 2nd Digit	3rd DOT Decimal Multiplier
BLACK	0	0	1
BROWN	1	1	10
RED	2	2	100
ORANGE	3	3	1,000
YELLOW	4	4	10,000
GREEN	5	5	
BLUE	6	6	
VIOLET	7	7	
GRAY	8	8	
WHITE	9	9	
GOLD	—	—	0.1
SILVER	—	—	0.01

AMERICAN WAR STANDARD & RMA 6 DOT COLOR CODE CHART

CAPACITY IN MICRO-MICROFARADS

COLOR	1st DOT 1st Digit	2nd DOT 2nd Digit	3rd DOT 3rd Digit	4th DOT Decimal Multiplier
BLACK	0	0	0	1
BROWN	1	1	1	10
RED	2	2	2	100
ORANGE	3	3	3	1,000
YELLOW	4	4	4	10,000
GREEN	5	5	5	
BLUE	6	6	6	
VIOLET	7	7	7	
GRAY	8	8	8	
WHITE	9	9	9	
GOLD	—	—	—	0.1
SILVER	—	—	—	0.01

RMA STANDARD COLOR CODE CHART for RESISTORS

COLOR	1st BAND 1st Digit	2nd BAND 2nd Digit	3rd BAND Decimal Multiplier
BLACK	0	0	1
BROWN	1	1	10
RED	2	2	100
ORANGE	3	3	1,000
YELLOW	4	4	10,000
GREEN	5	5	100,000
BLUE	6	6	1,000,000
VIOLET	7	7	10,000,000
GRAY	8	8	100,000,000
WHITE	9	9	1,000,000,000

FIG. 18-7. Color codes for mica condensers and resistors.

FIG 18–8 Link remote control unit type 1890 ed 2

tered on the carrier frequency A careful check on the tuning adjustments using a weak signal should correct the difficulty The receiver is now in tune except for the antenna tuning which must be adjusted upon installation.

(*c*) *Receiver failures.* With the squelch switch in the OFF position, the receiver normally emits a loud hiss when no carrier is being received and the tracing of this hiss through the receiver presents a simple method of localizing failures that might occur. If the r-f, mixer and high-frequency i-f tubes are removed from their sockets, most of the loud hiss should disappear. The remaining hiss is due to the noise generated in the grid circuit of the converter. When the 7AG7 i-f amplifier (V3) is plugged in, the hiss should rise nearly to maximum level. When mixer V2 is added, the hiss will increase slightly, apparently indicating that most of the noise comes from the high-frequency i-f stage. This is actually not true, since the noise generated in the grid circuit of the mixer merely overrides and masks the noise previously heard. When the r-f stage is added, a similar effect takes place but no increase in hiss level is normally heard since the second limiter is already saturated with noise. It is suggested that the service engineer familiarize himself with the sound of a normal receiver by removing the mixer, then the first i-f amplifier, and then the converter. Thereafter if a failure should occur in the receiver, he will be able to localize it by the absence of the hiss.

The operation of the entire receiver up to the grid circuit of the first limiter may be checked by noting the tuning meter readings with a signal applied to the input. Since the tuning meter at J1 measures the grid current of the first limiter, increase of the tuning meter reading with increase in signal input indicates that the receiver is operative up to that point. The gain of the receiver to the first limiter may be measured if a calibrated source of signal is available. It should require not more than one microvolt input to the antenna to cause a 40 microampere deflection in the tuning meter.

Vacuum tubes may vary considerably in efficiency at very high frequencies, therefore a check on the gain of the receiver should be made whenever one of them is changed. Tubes testers offer no sure method of testing tubes for operation at high frequencies and a much more rapid and satisfactory method of determining tube deterioration is by substituting a tube known to be good in place of the suspected tube and noting the difference in receiver operation.

Weakening of the squelch tube generally manifests itself in failure of the squelch circuit to close and therefore a need to change the setting of the squelch control in counterclockwise direction. Here, too, the best criterion for judging the efficiency of the tube is to substitute a tube known to be good in place of the one suspected.

Other failures that may arise would be of the well known resistor or capacitor failure type that should be easily localized by the service engineer since they manifest the same symptoms in an F-M receiver as in an amplitude modulated one.

18-4. Link Remote Control Units Type 1890 and 1938[4]—Remote control units type 1890 and 1938 are designed to furnish complete remote control of any Link radio main station equipment. Remote control unit type 1890 is used in the 30-44 mc range and type 1938 in the 72-76 or 152-162 mc ranges. Both the 1890 and 1938 units may be supplied in either of two types, i.e., A and B. The 1890-A or 1938-A provide complete control of a fixed station from a remote point. The 1890-B or 1938-B provide selection of either of two remote receivers as well as complete control of a remote fixed station equipment. All units are capable of providing control of all of the functions of transmission and reception over a single pair of telephone or similar type wires at distances up to approximately ten miles. A metallic two-wire circuit capable of carrying d-c voltages up to 100 volts at 10 ma is required when they are so connected. Alternate circuits including four-wire and simplex may also be used. These are shown in Figure 18-9.

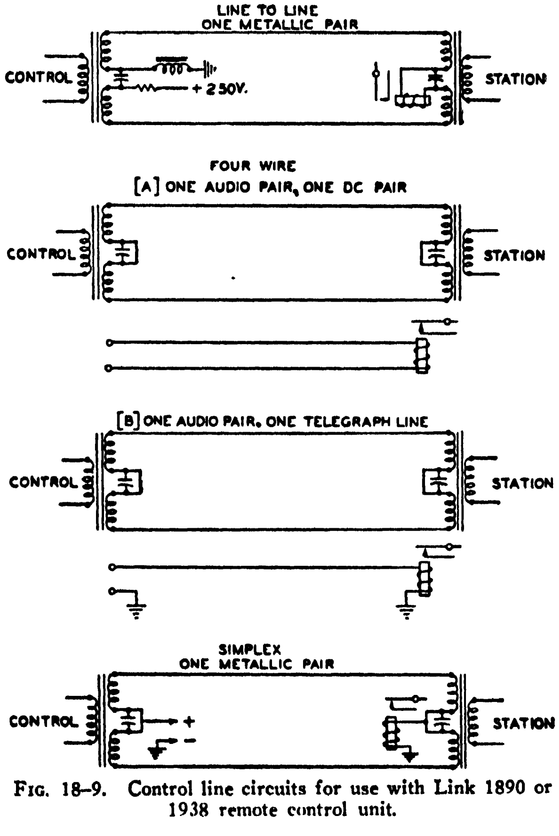


FIG. 18-9. Control line circuits for use with Link 1890 or 1938 remote control unit.

In addition to the control equipment proper, a device for indicating the presence of the carrier actually radiated by the transmitter is included. The effective range of this circuit varies with the power of the transmitter with which it is used, but in general will operate at two to four miles with a 50-watt transmitter and five to ten miles with a 250-watt set, depending to a great extent upon the type of pickup antenna employed. Power for either unit is derived from the standard 115-volt, 60-cycle power line.

Remote control units type 1890 and 1938 are housed in a sloping front cabinet designed for desk mounting. A handset and hang-up box assembly, with six feet of cable attached, is included. Both models of the 1890 and 1938 series control units (i.e. A and B) are mechanically identical and differ only in slight electrical changes. The physical and electrical characteristics of the units are as follows:

Line impedance: 500-600 ohms.
Line output level: Normal, + 8 VU, maximum, + 14 VU.
Receiver amplifier output: 2 watts into built-in speaker.
Carrier indicator frequency range:
  1890: Tunable to any frequency in 30-44 mc range.
  1938: Tunable to any frequency in either the 72-76 mc or 152-162 mc ranges by the addition of the proper crystal.
Carrier indicator sensitivity: Approx. 500 microvolts for both 1890 and 1938.

Remote control units type 1890 and 1938 can be considered electrically as made up of four separate parts, each of which performs a specific function. The first is the microphone amplifier, which possesses sufficient gain to amplify the output of the telephone handset or desk microphone to the required level for application to the control line. The microphone amplifier includes an automatic volume control circuit which limits the telephone line level and transmitter modulation to a predetermined value regardless of the sound intensity entering the microphone. The second is a similar circuit which amplifies the signal coming over the line from the receiver to a level which may be adjusted to give satisfactory volume in the speaker and handset receiver. The third, the carrier indicator, receives the signal radiated by the transmitter, amplifies it, and, by means of a vacuum-tube voltmeter circuit incorporated in the unit, actuates a meter on the front panel to give a visual indication of the presence and relative strength of a carrier. The fourth is the tone oscillator, which supplies a tone to the transmitter for attention, selective calling, or selective squelch signals. Correlation of the functions of these various subdivisions is accomplished

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[4] Link Radio Corporation, New York, N. Y.

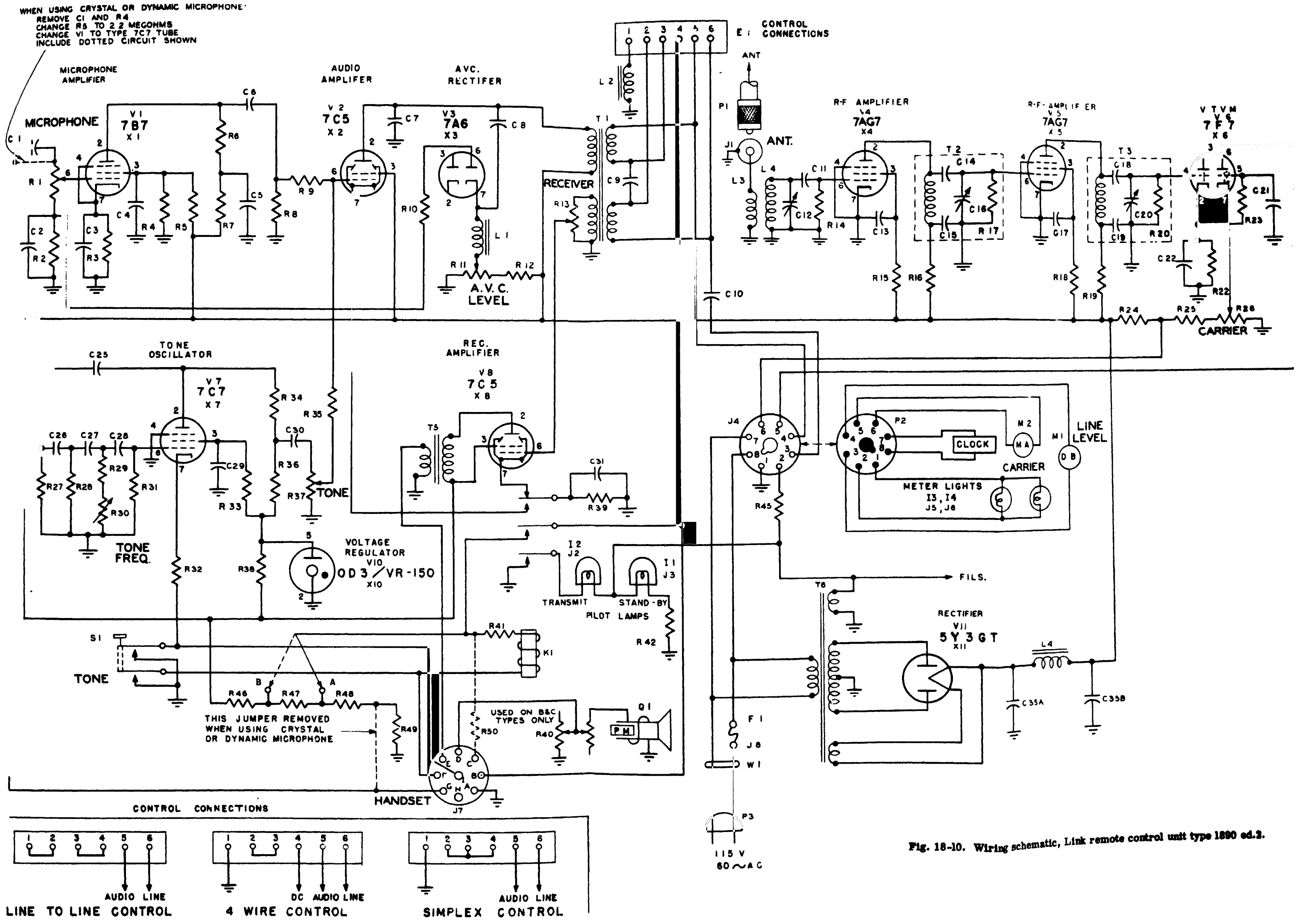

Fig. 18-10. Wiring schematic, Link remote control unit type 1890 ed.2.

by the control relay, which is operated by means of the push-to-talk button in the handset.

18–4a. Circuit Description

1. *Receiver Amplifier.* In the receiving condition, the telephone line is coupled to the loud-speaker in the control unit through a 7C5 tube (V8) which amplifies the normal line level (– 12 to + 8 VU) to a value sufficient to deliver full volume from the loud-speaker. The signal coming over the line from the receiver is connected to transformer T1 and through T1 to the grid of V8. The output of V8 is connected to the loud-speaker through transformer T5 and the contacts in the hang-up box, Figure 18–10. If the handset is lifted from the hook, the unit is transferred to the stand-by condition and the output of the receiver amplifier is removed from the loud-speaker and connected to the handset receiver.

2. *Microphone and Tone Amplifiers.* Two tubes are employed in the microphone amplifier to amplify the normal low level of the microphone to the required level. The handset microphone receives its current from the plate power supply at the junction of R48 and R49 on the voltage divider composed of R46, R47, R48, and R49. The resultant audio voltage developed across R49 is coupled through C1 to the grid of V1. If the control unit is supplied with a crystal microphone, the lead from C1 to the junction of R48–R49 is removed.

The output of V1 is fed to the grid of V2 by means of a conventional resistance-coupling circuit. V2 acts as an output amplifier for both voice input from V1, and tone input from V7. The gain of the voice amplifier is controlled by the MICROPHONE control potentiometer R1, located in the grid circuit of the 7B7. The output of this tube is fed to the line through transformer T1,

A portion of the output voltage of V2 is capacitively coupled to V3. The positive potential on the cathode of V3 is determined by the setting of AVC LEVEL control R11. Whenever the voice peaks appearing at the cathode exceed this potential, rectification occurs and the volume level at which this action begins can be adjusted by R11. This rectified voltage, applied as bias to the grid of V1, reduces the gain of V1 so that its output remains below a predetermined value. Reactor L1 is inserted in the rectifier circuit to smooth out the audio frequencies and cause an average bias voltage to be applied to the grid of V1. The grid circuit of V1 contains a timing circuit composed of R2 and C2 which is designed to hold the grid of V1 biased for a brief period so that the gain of the amplifier will not fluctuate between speech syllables.

Besides the voice input to V2, there is also tone input from the self-contained tone oscillator V7. The level of this voltage is adjusted by the TONE control R37. In the standby condition, V2 is disabled by opening its cathode circuit. It operates only when the self-biasing circuit (R39–C31) is tranferred from the cathode of the receiver amplifier (V8) to the cathode of the audio amplifier (V2) when the relay coil is energized. In addition to accomplishing this tranfer, the relay lights the red pilot lamp on the front panel and applies a d-c voltage to the telephone line for controlling the transmitter. This voltage is derived from the plate voltage source at the junction of R47–R48 on the voltage divider.

3. *Tone Oscillator.* The tone oscillator consists of a 7C7 tube in a phase shift circuit. Oscillation is produced by causing a 180 degree phase shift to occur in the resistor-condenser network between the plate and the grid of V7. The frequency at which this phase shift occurs is determined by the resistor and condenser values in the network.

If it is neceessary to check the frequency of the tone oscillator, connect an oscilloscope across the audio line terminals (5 and 6 on terminal strip) and use an accurately calibrated audio oscillator to establish the correct frequency.

The volume of the tone output is regulated by the TONE control potentiometer R37, in the grid circuit of audio amplifier V2.

When the TONE switch (S1) is depressed, the cathode circuit of the tone oscillator is completed and relay K1 is energized; resulting in the production and transmission of an audio tone. The same function may be accomplished by depressing the handset push-switch while the handset remains on its hook.

4. *Carrier Indicator*

(*a*) *Remote control unit type 1890.* In remote control unit type 1890 the carrier indicator consists of a two-stage r-f amplifier, a vacuum tube voltmeter and a 5-ma d-c meter mounted on the front panel. The signal is coupled to the grid of the first r-f amplifier V4 through the antenna matching transformer L3–L4. The output of V4 is capacitively coupled to the grid of the second amplifier V5 which in turn amplifies the signal and feeds it to the grid of the first half of the VTVM tube V6 which acts as a diode rectifier. The resultant d-c voltage developed across R22 is applied to the grid of the second half of the 7F7 through the limiting resistor R23. This portion of the tube is triode-connected and is normally biased almost to cutoff, the bias being adjusted by potentiometer R26. Since an incoming signal causes a voltage of positive polarity to be impressed on the grid, and since the meter is in the plate circuit of the tube, the meter reading will be approximately proportional to signal strength.

(*b*) *Remote control unit type 1938.* In remote control unit type 1938 the carrier indicator consists of an oscillator-frequency multiplier stage, a mixer stage, a stage of i-f amplification, a vacuum tube voltmeter, and a 0.5 ma d-c meter mounted on the front panel. The signal is mixed in V4 with the output of the oscillator V9. For operation in the 152–162 mc band, a 5-mc i.f. is produced in the mixer by the heterodyning of the carrier and the eighteenth harmonic of the crystal. (This harmonic is obtained by tuning the plate circuit of V9 to the sixth harmonic of the crystal and the third harmonic of the plate circuit is used for mixing.) For operation in the 72–76 mc band, the oscillator-frequency multiplier output is the tenth harmonic of the crystal and this frequency is heterodyned with the carrier in V4 which also produces a 5-mc i.f. The i-f frequency undergoes a stage of amplification in V5, another 7AG7, and is then fed to the grid of the first half of the VTVM tube V6 which acts as a diode rectifier. The resultant d-c voltage developed across R22 is applied to the grid of the second half of the 7F7 through limiting resistor R23. This half of the tube is triode-connected and normally biased almost to cutoff, the bias being adjusted by potentiometer R26. Since an incoming signal causes a voltage of positive polarity to be impressed on the grid, and since this meter is in the plate circuit of the tube, the meter reading will be approximately proportional to signal strength.

5. *Power Supply.* A self-contained vacuum-tube rectifier-type power unit provides the necessary d-c potential to operate the amplifier and control circuits. A type 5Y3GT tube is used in a full-wave rectifier circuit and its output is filtered by means of a single-section condenser input filter. A line fuse is provided to prevent damage to the components and is located on the rear edge of the chassis.

6. *1890-B and 1938-B.* The circuit of the B type unit is identical to that described in the above paragraphs except for the modifications required for the selections of either of two remote receivers. This is accomplished as follows:

When the handset is lifted from its switch hook, a pair of contacts on the switch hook connect the tap on the power supply bleeder between R46 and R47 to the control line through a 33,000-ohm resistor (R50) causing a current of 3 ma to flow in the line and thus operate the squelch control relay in the receiver located at the station equipment. When the handset push-button is pressed, the control relay K1 short-circuits this resistor (R50) and applies the full voltage of the tap to the line.

When the proper termination of 10,000 ohms is connected at the station equipment end of the control line, voltages of 30 for the first case and 90 for the second are normal. Automatic opening of the squelch and/or muting of one of the receivers in the station equipment (where two-frequency signal monitoring is used) whenever the handset is lifted from its switch hook is thus provided.

Changing from the A to B types is easily accomplished in the field by removing the bottom plate, changing one connection, and adding resistor R50 as shown in Figure 18–10.

18–4b. Maintenance and Service—Maintenance of remote control units 1890 and 1938 consists mainly of tube replacement and relay cleaning when required. Tubes need not be replaced periodically but rather as indicated by a reduction in performance of the particular part of the circuit in question. Since tubes age gradually, an indication of the approaching end of their useful life will be given by the necessity for increased gain control settings (in the case of the 7B7 and 7C5 audio amplifiers) coupled with increasing distortion and lower maximum output. Tubes displaying these symptoms to a marked degree should be replaced.

A gradual reduction in supply voltage due to weakening of the rectifier tube will also cause similar effects. The condition of this tube may be checked by replacing it and observing the results aurally or by measuring the control voltages across the control line by means of a d-c voltmeter.

The tubes in the carrier indicator may be checked against the carrier meter reading in the following manner. With no signal impressed, rotate the CARRIER control for maximum deflection. If the maximum scale reading is below the midway mark on the carrier meter V6 should be replaced. If the normal

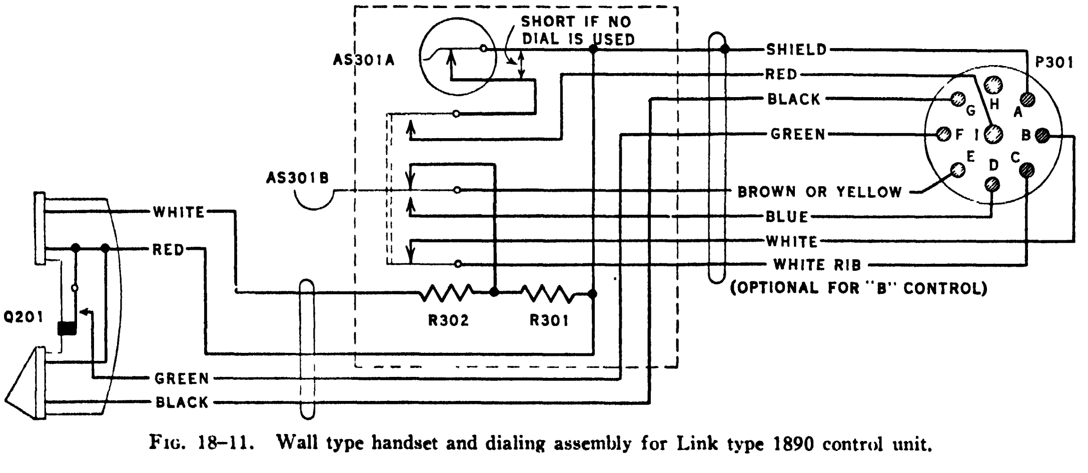

FIG. 18–11. Wall type handset and dialing assembly for Link type 1890 control unit.

carrier-on reading gradually becomes lower as the length of time the unit is in service increases, one or both the r-f amplifier tubes in the 1890 unit or one of the 7AG7's in the carrier indicator section of the 1938 unit will require replacement if it is not possible to retain the mid-scale reading by retuning the amplifier circuits. This assumes that the transmitter output remains at its normal level. Noisy operation of the control unit will also result from dirty relay contacts. This effect will be more prevalent in units operating under conditions of high humidity or in corrosive atmospheres. Contact cleaning will remedy this effect, but preventive measures, such as installation in a dry location will be found more satisfactory. In case of failure of the control unit to operate, the tubes should first be checked. If the tubes are found to be satisfactory the relay contacts should be cleaned and lightly burnished. If the unit still fails to operate, invert; remove the screws holding the bottom plate in place, and check the circuit for short-circuited capacitors, open resistors or transformers and general circuit continuity as shown on the circuit diagram.

18-5. Increasing the Coverage of Police Radio Networks—To insure the maximum possible coverage, with due regard to the economics of the system, it frequently becomes necessary to resort to automatically operated relay stations located at strategic points. Occasionally the use of a directive antenna system as the radiator at the repeater station will solve a difficult coverage problem.

From a topographical standpoint, the problem encountered by the California Highway Patrol is of particular interest since California has great extremes in elevation; Mt. Whitney towering 14,996 feet above sea level and Death Valley 300 feet below sea level; the highest and lowest points in the Continental United States. Moreover California is traversed for almost its entire length by two major ranges of mountains, the Coastal range and the Cascade-Sierra Nevada range. The Coastal range follows quite closely the coast line and the other ranges located at distances varying from 100 to 300 miles inland. A major highway extends the entire length of the state from the Mexican border to the Oregon line lying between the coast range and the ocean. Also, between the Coastal range and the Cascade-Sierra Nevada range there is still another major highway and both of these highways are approximately 900 miles in length. These two major highways carry a large portion of the state's north-south traffic, and it was necessary to give thorough consideration to an adequate two-way coverage of these routes.

Many portions of the state, particularly the northern section, are almost continuous expanses of mountainous country with relatively small sections of valley territory which, in turn, are surrounded by high mountains ranging in elevation up to 8000 or 9000 feet. There are 117,760 miles of roads and highways in the 158,693 square miles embracing the state.

California is divided into 58 counties, and many of these county lines extend completely through one of the major ranges of the mountains. In every instance it was necessary to plan on providing for two-way coverage from, as nearly as possible, all points in a given county to a central county office or dispatching point. The manner in which this communication problem was met successfully has been explained by R. A. Kridler, Supervisor of the Southern part of the State of California, in *Electronic Industries*.[5]

In order to increase the coverage, fifteen automatic radio relay stations have been installed in various parts of the state. These stations operate on a frequency of 118.55 mc and are located at elevations ranging from 2600 feet to 6150 feet. An excellent degree of coverage is reported; moreover, experience has shown that distances quite beyond the line of sight are obtainable with the 118.55 mc channel. The 118.55 mc transmitters, operating with a rated output of ten watts from the output terminals, are controlled by an associated receiver tuned to a frequency of 39.78 which is used by the highway patrol throughout the state. The 118.55-mc transmitter antenna is a half-wave vertical coaxial type radiator. The receiving antenna is of the same type with the proper dimensions for the 39.78-mc channel. The need for service and maintenance of these unattended relay stations has been, on the average, once a month.

18-6. Use of 60° Corner Reflector—An operating problem was encountered when repeater stations were installed at Mt. Diablo and Blue Canyon to provide better reception in Sacramento from F-M mobile units operating on the 39.78-mc channel in remote areas.

The method by which this problem was solved has been described by Mr. E. Stewart Naschke, Supervising Operator of the California Highway Patrol, and quoted here with his permission as well as the permission of *Electronics*, in which his original paper appeared.[6]

> "Repeater stations transmitting on 118,550 kc have recently been installed at Mt. Diablo and Blue Canyon, California, to provide better reception in Sacramento of mobile police units operating on 39,780 kc in remote areas.
>
> "Sacramento and the two repeater transmitter sites are nearly in a straight line with respect to each other, lacking only about 15 degrees of being so situated. The city lies approximately 65 miles southwest of Blue Canyon and 52 miles northeast of Mt. Diablo.
>
> "Both repeater station sites overlook the Sacramento Valley and this created a problem. It was found that transmissions from FM mobile units working in certain areas near the two automatic stations sometimes turned

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[5] "Radio Relay Links in Police Work," R. A. Kridler, California Highway Patrol, Los Angeles, *Electronic Industries*, June 1944.

[6] "Police Satellite System," E. Stewart Naschke, *Electronics*, May, 1944.

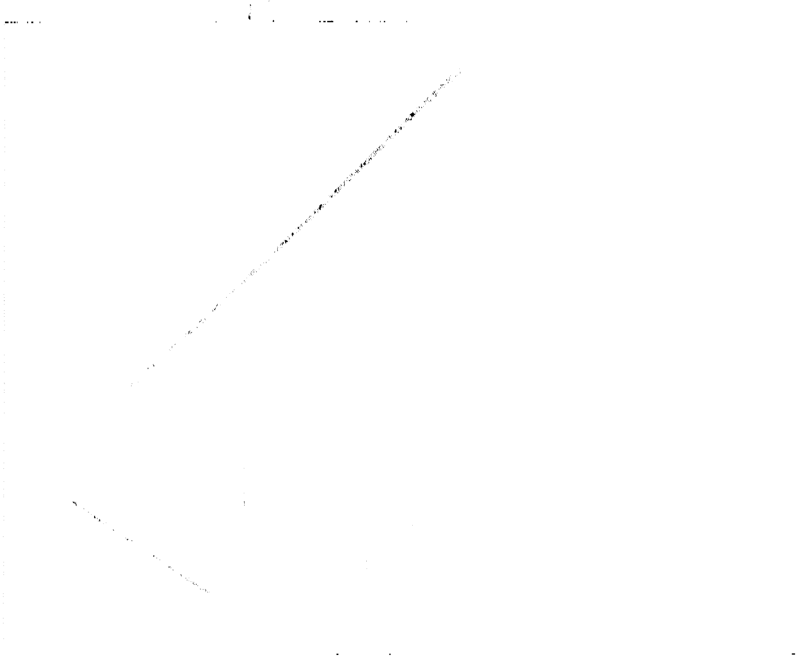

FIG. 18-12. One of the two unidirectional 118-mc arrays used at Sacramento for receiving signals relayed by the Mt. Diablo and Blue Canyon repeater stations. Use of a coaxial antenna permits the entire assembly to be built around a single support-point, facilitating orientation.

on both repeater transmitters. However, satisfactory limiter action would not always be realized in both control receivers and the transmission from the repeater station so affected would be more noise than intelligible signal.

"Since the carrier strength of the 10-watt Mt. Diablo and Blue Canyon F-M transmitters is substantially the same, the ultimate signal realized at the loudspeaker connected to the Sacramento receiver was in many cases unintelligible. This fact caused no end of difficulty to the operators on duty at the monitoring point.

"This problem led to a search for unidirectional receiving antennas for use at Sacramento, one to receive Mt. Diablo and block out Blue Canyon, and the other to receive Blue Canyon and discriminate against Mt. Diablo.

"*Antenna Array Design.* Circumstances made it desirable that each antenna system match the input of available F-M receivers; that it require little space for mounting and be unaffected by weather. Before the final design resulted, experiments were conducted with three-element reflector-director arrays and simple parabolic reflectors with little or no success.

"First experiments with a square-corner reflector also left much to be desired. The chief difficulty experienced with experimental models was the lack of sufficiently high front-to-back ratio. While field strength ratios of two-to-one in the case of frequency-modulated signals are usually sufficient to cause the elimination of the weaker signal, reflections from nearby steel objects and buildings prevented realization of the desired results.

"Later, attention was drawn to data on square-corner reflectors by Kraus and Terman. Accordingly, a sixty-degree corner reflector antenna was designed, utilizing this data.

"First trials with this antenna were disappointing. The same difficulty as before was experienced—too low front-to-back ratio. However, the addition of auxiliary reflector and director elements placed a quarter wave behind and a quarter wave in front of the coaxial element gave surprising results. It was possible to eliminate one of the repeater transmitter signals while receiving the other.

"Later tests proved that the auxiliary reflector element was unnecessary and so it was eliminated in the final design. Figure 18-12 shows how it was possible to build such an antenna system using a single support, and Figure 18-13 shows the dimensions of the various elements of the system.

"*Test Results.* Table I and Figure 18-14 illustrate the effect of rotating either antenna system with respect to the transmitter which it normally receives, together

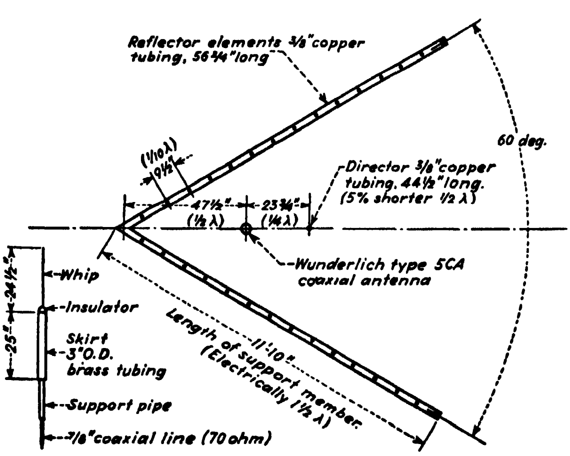
Reflector elements 3/8" copper tubing, 56 3/4" long
60 deg.
(1/10 λ)
9 1/2"
Director 3/8" copper tubing, 44 1/2" long. (5% shorter 1/2 λ)
47 1/2"
(1/2 λ)
23 3/4"
(1/4 λ)
Wunderlich type 5CA coaxial antenna
Whip
24 1/2"
Insulator
25"
Skirt 3" O.D. brass tubing
Support pipe
7/8" coaxial line (70 ohm)
Length of support member 11'10" (Electrically 1 1/2 λ)

FIG. 18-13. Details of the receiving array pictured in Figure 18-12. The frame is constructed of maple and birch.

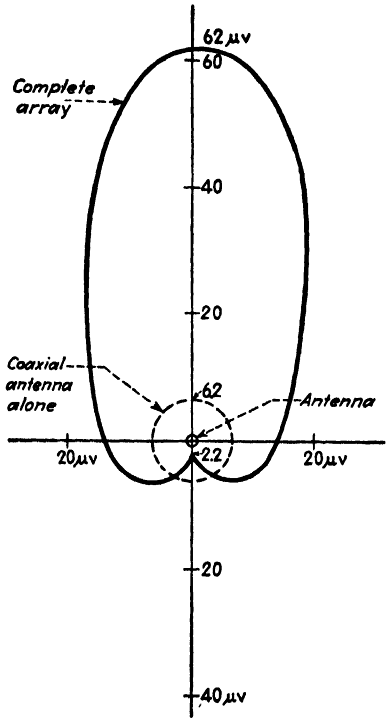

FIG. 18–14. Field-strength pattern of the 60-degree corner reflector array and, for comparison, the pattern of the coaxial antenna alone.

with the effect of removing the auxiliary director element.

"The meter readings given were taken in the grid circuit of the first 455-kc i-f amplifier of a Motorola FSR-16B receiver with a high-frequency converter unit added to the front end.

"Initial antenna gain estimates, based on receiver sensitivity curves furnished by the manufacturer, indicated an antenna gain of 15 times, or 23 db. The indicated front-to-back ratio was 52.5 to 1, or approximately 34 db. More precise measurements of the gain of the antenna array and front-to-back ratio have since been made, utilizing a Ferris microvolter as a standard signal generator. These measurements show a 20 db gain over the dipole antenna. The measured front-to-back ratio is 30 db.

"It will be noticed from Figure 18–14 that the angle of maximum signal strength is broad, whereas the angle of minimum signal strength is relatively sharp. In adjusting the two receiving arrays at Sacramento best results were obtained by orienting them for minimum signal from the undesired station.

"Installation of the two directional receiving arrays has proven well worth while. It not only has reduced the number of unintelligible messages caused by interfering signals but has also improved the signal-to-noise ratio and the tone quality on signals received through the repeater stations. This latter fact is attributed to increased saturation of the limiters in the 118-mc F-M receivers.

"*System Operation.* The audio-frequency output from each of the two 118-mc receivers used at Sacramento is brought into the control room on separate lines and fed into two separate speakers through a control network. A 39,780-kc F-M receiver used to pick up transmissions direct from local cars is also fed into the monitoring position.

TABLE I. RELATIVE SIGNAL STRENGTHS FOR VARIOUS POSITIONS OF ANTENNA ARRAY WITH RESPECT TO DISTANT TRANSMITTER

ANTENNA POSITION	METER READINGS (see text)	
	With Aux. Director (μa)	Without Aux. Director (μa)
Maximum signal	9.5	9
Minimum signal	2.0	6
Midway between minimum and maximum signal positions	6	6

"It has been found that by placing the three speakers along the top of the operating desk and separating them from 12 to 18 inches, the operator is able to tell by audible means which speaker is producing the best signal. This being determined, the operator presses the lever switch at his left corresponding to the speaker producing the best signal. This silences the remaining speakers.

"A fourth lever-type switch labeled 'Mute,' when depressed, attenuates the output of all speakers approximately 25 db. This permits the operator to answer the telephone or speak over the interoffice communicating system.

"Indicator lamps above the switches provide an additional check. When the switches are in normal monitoring position, all channels open, the green lamps are lit. Red lamps show which switches are off normal settings."

18–7. Link Mobile Radio Equipment Type 25– or 50–FMTR–7C[7] —Frequency-modulated mobile radio equipment type 50-FMTR-7C (or 25-FMTR-7C) is a complete assembly designed for mobile two-way communication on the 152–162 mc very-high-frequency band. It consists of radio transmitter type 2240 (or 1906 ed. 2), radio receiver type 1905, and all accessories for accomplishing an operating two-way communication system in a mobile unit. The equipment is designed normally to derive all of its primary energy from the 6-volt, 3-cell lead storage battery available in such units. Also available are 12- and 24-volt models.

Frequency modulated mobile equipments type 25-FMTR-7C and 50-FMTR-7C differ only in that the former uses radio transmitter type 1906 ed. 2 and the latter uses radio transmitter type 2240. These two transmitters are identical in all respects except for the size and rating of the dynamotor and the power output rating of the transmitter. Radio transmitter type 1906 ed. 2 uses a 400 volt dynamotor and has a nominal output rating of 25 watts. Radio transmitter type 2240 uses a much larger (500 volt) dynamotor and has a nominal output rating of 50 watts. Inasmuch as the equipments are identical in all other respects, the following material will be written in terms of the higher powered unit and any differences to be found in the lower powered unit will be carried in parenthesis.

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[7] Link Radio Corporation, New York, N. Y.

Radio transmitter type 2240 (or 1906 ed. 2) is a 50-watt (or 25-watt) (nominal output) frequency-modulated unit, designed especially for mobile use. Its more salient characteristics are:

Power output: 50 watts (or 25 watts).

Frequency range: 152–162 mc.

Type of emission: Frequency modulated.

Frequency deviation: ± 20 kc.

System audio response: 500–3000 cycles, ± 1 db. 350–5000 cycles, ± 2.5 db.

Weight: 21 pounds (or 17½ pounds).

Over-all size: 8 inches high, 10 inches deep, 12¼ inches long.

Tube types: 1-7F7, 1-7AG7, 1-7W7, 2-2E26, 1-829-B.

Power supply: Self-contained dynamotor.

Power input

Standby: 6.0 v at 5 amp.

Transmitting: 6.0 v at 43 amp. (or 32 amp).

Mounting: Quick-release base assembly.

Output impedance: Any—usually fed into concentric line.

Control: Remote by self-contained relays—provisions for co-ordinated receiver control.

Radio transmitter type 2240 (or 1906 ed. 2) utilizes the phase-shift method of obtaining the desired frequency deviation. This method permits direct crystal control of the carrier frequency and a simple circuit design with no critical tuning adjustments. A carrier power considerably in excess of the rated output is available under normal operating conditions in mobile service. The transmitter is entirely self-contained and utilizes a dynamotor to convert the six-volt input to high voltage for the plate supply for the tubes. Six tubes are included on the chassis, three of which are of the low-drain receiving type.

All tuning adjustments are straightforward, and small errors in making them will not affect the output frequency, quality, or modulation level in any way.

Radio receiver type 1905 is a 13-tube, crystal-controlled, single-frequency frequency-modulation superheterodyne receiver designed particularly for the reception of frequency-modulated signals of the type generated by transmitters type 1906, and 2240. Some pertinent characteristics are:

Frequency range: 152–162 mc.

Type of signal: Frequency modulated.

Frequency deviation: ± 20 kc.

System audio response: 500–3000 cycles, ±1 db. 350–5000 cycles, ± 2.5 db.

Tube complement: (2) 6AK5 (6) 7AG7 (2) 7A6 (1) 7C7 (1) 7F7 (1) 7B5.

Power supply: Self-contained vibrator.

Power input: 6.0 v at approximately 6 amp.

Output impedance: 4 ohms.

Mounting: Quick-release base assembly.

Control: Remote—co-ordinated with transmitter control.

Weight: 23½ pounds.

Size: 8 inches high, 10 inches deep, 12¼ inches long.

Undistorted power output: 1 watt.

A quartz crystal is employed to insure stable receiving conditions under all variations of temperature and humidity as well as the severe vibration encountered in mobile service. The double i-f system makes possible excellent band-pass characteristics with a very favorable image ratio.

Three tuning meter connections are provided. The first is for measuring the grid current of the first limiter, indicating resonance in all the preceding stages. The second is for measuring grid current in the second limiter and the third is to permit adjustment of the balance of the discriminator circuit. The power supply is of the synchronous vibrator type, providing a most efficient and economical method of obtaining all B voltages for the receiver.

18–7a. Circuit Description

1. *Radio Transmitter Type 2240 (or 1906 ed. 2).* Radio transmitter type 2240 (or 1906 ed. 2) is a frequency-modulated unit utilizing the phase-shift method of obtaining frequency deviations, and as such exhibits considerably different characteristics than the usual amplitude-modulated units. Intelligence is conveyed in frequency variations of the constant-amplitude carrier wave. The use of the phase-shift method of frequency modulation allows direct crystal control of the mean carrier frequency, a necessity in unattended and mobile equipment. It necessitates, however, considerable frequency multiplication after the modulator to generate sufficient frequency deviation. A number of small, low drain tubes are used for this function, and a total frequency multiplication of 48 times is effected.

In working with F-M transmitters, certain handicaps are encountered that make unusable many of the "rules-of-thumb" that have been helpful in servicing amplitude-modulated equipment. Oscilloscopes are of little value in checking, since no change of pattern is discernible during modulation. In fact, modulation is accompanied by no readily measurable change of any kind in the r-f output of the transmitter.

(*a*) *Oscillator-modulator.* The twin triode 7F7 (V-1) acts as both crystal oscillator and phase modulator. The first half of the tube operates in a resistance-coupled aperiodic oscillator circuit. The crystal, which is connected between grid and plate, operates on the 48th sub-harmonic of the output frequency. Since the output frequency range is 152–162 mc, the crystal frequency will lie between 3166.67 and 3375.0 kc.

The second half of the 7F7 acts as a phase modulator. The r-f output of the crystal oscillator is impressed on the phase-modulator grid by means of the blocking condenser C4. The cathode circuit is

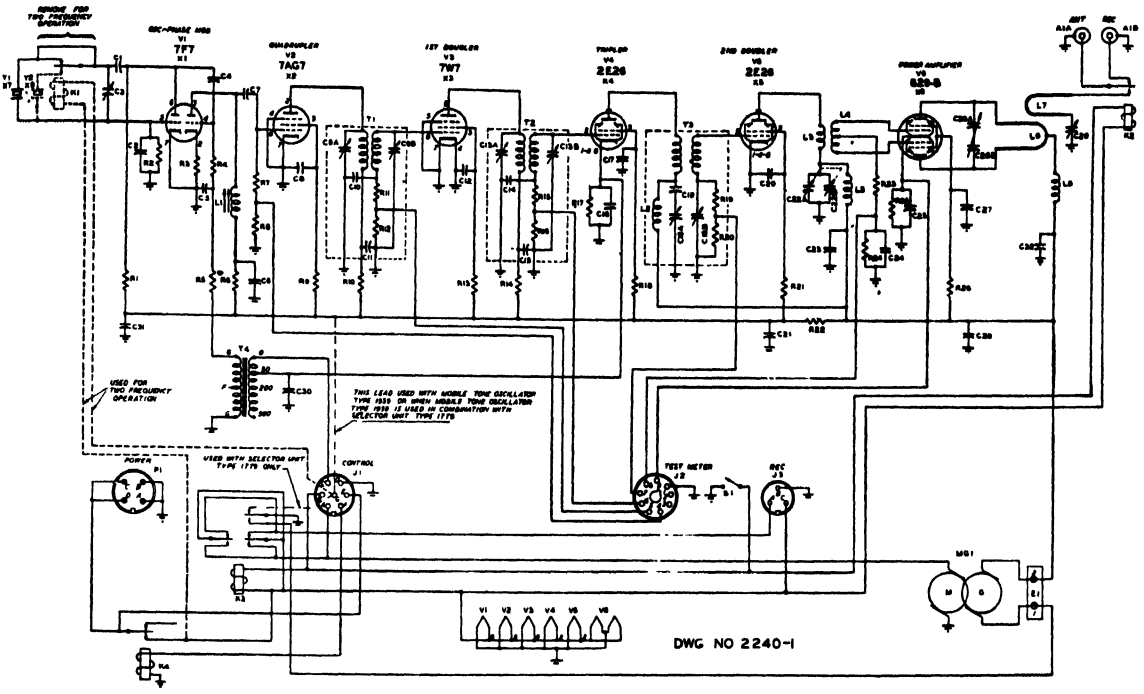

FIG. 18–15. Schematic diagram, Link transmitter type 2240 (or 1906 ed. 2).

provided with a large amount of degeneration by unbypassed resistor R3. Because of this degenerative feedback, the transconductance of the triode is abnormally low—so low that the plate current is affected about as much by the direct grid-plate capacitance as by the transconductance. The two effects result in plate current vectors almost 180° apart, and the total plate current is the resultant of the two components. In phase it will be about 90° removed from the phase of the voltage impressed on the grid.

When audio is impressed on the grid thereby periodically changing the bias, and in consequence the transconductance, the plate current undergoes a periodic change in both amplitude and phase. The amplitude modulation is unimportant, and is removed in the frequency multipliers, but the phase modulation remains and is the essential element of the transmitted signal.

The phase modulation is modified by the use of a frequency correcting circuit consisting of resistors R4 and R5 and the condenser C5. These elements are connected between the grid and the microphone transformer, which is driven directly by the external microphone. The frequency-correcting circuit is introduced because the frequency-deviation brought about by phase modulation is linearly proportional to frequency, and pure phase modulation would become troublesome at high audio frequencies. The correcting circuit causes the deviation vs. frequency curve to begin to flatten out above 3000 cycles.

(*b*) *Frequency multipliers.* The frequency deviation which may be produced in a phase modulator such as described above is relatively small, usually not more than a value equal to the modulating frequency (otherwise severe distortion is encountered). To get sufficient deviation (± 20 kc), the frequency of the modulated wave must be multiplied considerably. In the 2240 (or 1906 ed. 2) transmitter, it is multiplied by 48. Multiplication is accomplished by a 7AG7 quadrupler (V2), a 7W7 doubler (V3), a 2E26 tripler (V4), a 2E26 doubler (V5), and the power amplifier, an 829-B (V6). The grid drive in each case is well above saturation, so that slight changes in tuning or reduction in tube emission can have little effect on succeeding stages.

(*c*) *Driver and power amplifier.* The 2E26 doubler, mentioned in the paragraph above, is used to drive the push-pull power amplifier 829-B (V6). The plate circuit of the 2E26 is inductively coupled to the grid coil of the power amplifier, and tuning is effected by condenser C22 in the 2E26 plate circuit. The antenna circuit is inductively coupled to the plate tank, which is tuned by condenser C26. Antenna loading is varied by means of the antenna loading condenser C29.

Provision has been made in all stages to read grid current by means of test meter unit type 2015A. In addition, the cathode current of the power amplifier may be read on the meter to facilitate tuning the PA and antenna circuits.

(*d*) *Control and power circuits.* All plate power for radio transmitter type 2240 (or 1906 ed. 2) is supplied by the 6-volt dynamotor, MG1. C28 serves as a high-voltage filter condenser for the dynamotor. The transmitter has sufficient relay circuits for complete remote control and in addition is designed to provide all necessary relay and control functions for radio receiver type 1905. The normal operating sequence is as follows:

(1) Relay K4 is energized by applying "hot" 6 volts to contact F on the control plug J1. This is accomplished in the remote control head by turning on the volume control switch.

(2) Relay K4 energizes the transmitter filaments, the receiver filaments through contact C on the receiver plug J3 and the receiver power supply through the back contacts on relay K3 and contact A on the receiver plug. The receiver is now in full operation and the transmitter filaments are warm. Antenna connection is made to the receiver through the back contact of relay K2.

(3) In order to transmit relay K3 is energized through contact B on the control plug and the microphone push-to-talk button. The transmitter may also be turned on by means of the toggle switch located on the front of the chassis. This switch is used when tuning or making other adjustments.

(4) Relay K3 breaks the receiver power supply primary voltage, thus muting the receiver. It also applies primary energy to the dynamotor MG1 which supplies the entire transmitter with high voltage; and at the same time it energizes relay K2. A third function is performed by this relay since it also keys the dynamotor high voltage return circuits. This high voltage break is necessary to key the transmitter rapidly and allow rapid transfer from transmit to receive. The additional back contact on this relay provides lock-in for the alarm relay in selector unit type 1779, when used, for automatic resetting of the selective calling equipment. Additional information on selective calling equipment may be procured, if desired, from the Engineering Dept. of Link Radio Corporation.

(5) Relay K2 transfers the antenna from receiver to transmitter.

2. *Radio Receiver Type 1905.* Radio receiver type 1905 is designed to receive signals wherein the intelligence is conveyed in variations of carrier *frequency* about a mean frequency instead of in variations of the *amplitude* of the carrier about a mean level as in amplitude modulation. There are only three fundamental differences between frequency- and amplitude-modulation receivers.

The first difference is in the band-pass characteristics. Since the carrier frequency varies over a band of plus and minus 20 kc from the mean carrier frequency, the receiver has to accept a band at least 40 kc wide. Thus the intermediate-frequency transformers are designed to pass a relatively wide band of frequencies compared to an A–M receiver.

The second difference is that, since only variations in frequency are to be converted into intelligence, amplitude variations of the signal must be removed. This function is accomplished by the limiters. They are, in effect, saturated amplifiers so that increasing the input to them above a certain level will cause no increase in their output. Thus they "limit" the magnitude of the signal applied to the discriminator to a constant level. The excellent signal-to-noise ratio of the 1905 receiver is largely due to the use of two cascaded limiters. On signals too weak to effectively saturate the first limiter, the second limiter is already saturated and ironing out whatever amplitude noise variations the first limiter has permitted to pass.

The third difference is in the method of detection; i.e., the conversion of frequency variations into audio frequencies. This function is accomplished by the discriminator transformer T106 and the 7A6 detector.

(*a*) *R-f amplification and mixing.* The antenna input of radio receiver type 1905 is designed to feed from a 50-ohm concentric line. A type 6AK5 (V101) serves as a high gain r-f amplifier with both grid and plate circuits tuned for maximum efficiency. The output of the r-f amplifier is converted to the first i-f frequency of 47.4 to 50.6 mc in the following 6AK5 first mixer (V102) by beating against the output of the 7AG7 doubler (V113). The grid circuit of the doubler is inductively coupled to the plate circuit of the oscillator-multiplier (V112), which is tuned to the sixth harmonic of the crystal used. The frequency of the oscillator is 52.4 to 55.6 mc, and the doubler, 104.8 to 111.2 mc. The output of the doubler is inductively coupled into the first mixer, while the output of the oscillator is capacitively coupled into the 7AG7 second mixer (V104). One stage of amplifiation is provided at the first i-f frequency, using a 7AG7 (V103) as amplifier. Its output is applied to the second mixer, where a 5000-kc intermediate frequency is obtained by beating against the output of the oscillator-multiplier.

A stage of amplification at 5000 kc is employed, using a 7AG7 tube (V105). This is followed by the first and second limiters, (V106 and V107) employing a 7AG7 and 7C7 respectively.

(*b*) *Limiters.* The circuit and actions of the two limiter stages are identical. Both tubes are operated at low plate and screen voltage and without bias except that derived from the grid leak and condenser combinations R117–C124 and R121–C130. These stages act as class C amplifiers, giving no increase in output current or voltage once the impressed grid voltage has exceeded a threshold value of 2 volts rms. Voltages above this value cause increasing rectification in the grid circuit, automatically setting up a bias to limit the peak plate current. Due to the low plate and screen voltages saturation occurs at a low level of grid voltage. The time constant of the grid leak and condenser is chosen to be long compared to i-f frequency (5000 kc.) but short enough to follow rapidly fluc-

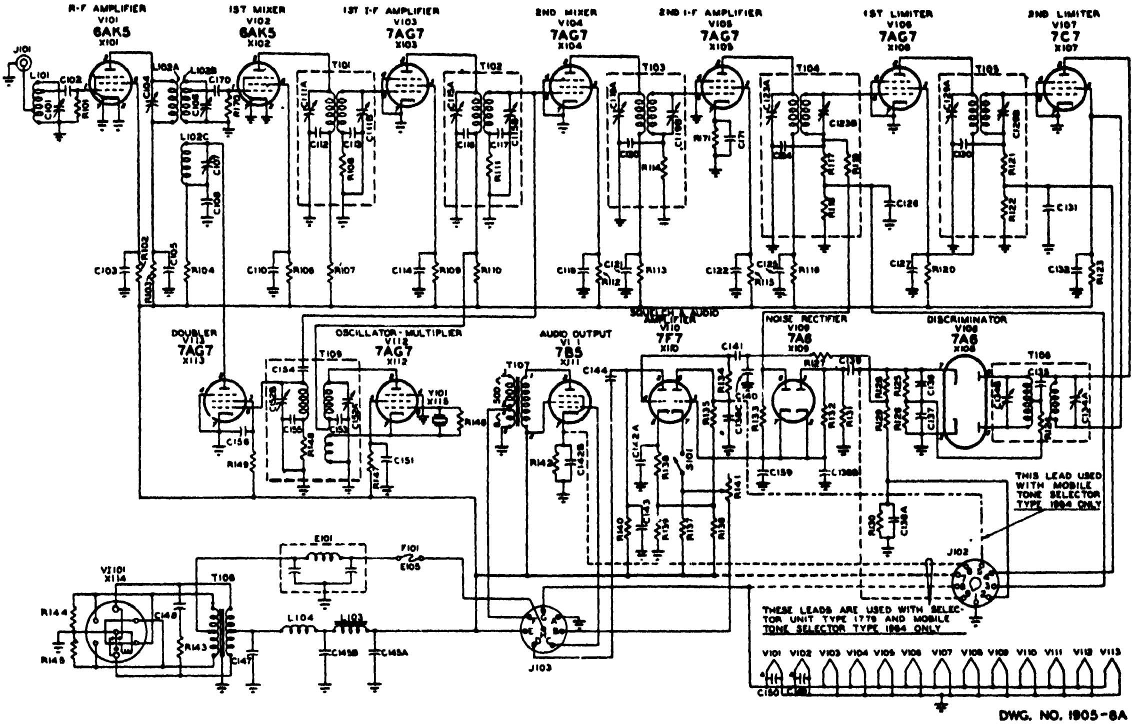
R-F AMPLIFIER V101 6AK5 X101
1ST MIXER V102 6AK5 X102
1ST I-F AMPLIFIER V103 7AG7 X103
2ND MIXER V104 7AG7 X104
2ND I-F AMPLIFIER V105 7AG7 X105
1ST LIMITER V106 7AG7 X106
2ND LIMITER V107 7C7 X107
J101
T101
T102
T103
T104
T105
DOUBLER V113 7AG7 X113
OSCILLATOR-MULTIPLIER V112 7AG7 X112
T109
Y101 X115
AUDIO OUTPUT V111 7B5 X111
T107
SQUELCH & AUDIO AMPLIFIER V110 7F7 X110
NOISE RECTIFIER V109 7A6 X109
DISCRIMINATOR V108 7A6 X108
T106
THIS LEAD USED WITH MOBILE TONE SELECTOR TYPE 1984 ONLY
J102
THESE LEADS ARE USED WITH SELECTOR UNIT TYPE 1779 AND MOBILE TONE SELECTOR TYPE 1984 ONLY
V1101 X114
T108
E101
F101
E105
L104
L103
J103
V101 V102 V103 V104 V105 V106 V107 V108 V109 V110 V111 V112 V113
DWG. NO. 1905-8A

FIG. 18-16. Schematic diagram, Link receiver type 1905.

tuating, high-frequency noise peaks. By cascading two such stages, the limiting effect of one tube is multiplied by the limiting effect of the other and essentially perfect limiting is obtained. Furthermore, by properly proportioning the circuit constants of the first limiter, the input to the second limiter grid is maintained at the optimum voltage for most effective action.

The grid return circuits of all the r-f and i-f tubes contain high resistances. By this means, blocking of any of the stages on strong signals is is eliminated due to the bias developed across these resistors as soon as the associated grid draws current. A further advantage of this method is that as the incoming signal strength is increased, the tubes ahead of the first limiter will also act as limiters as soon as their grids draw current.

Sufficient gain is incorporated in the receiver so that the smallest incoming signal which could be considered comparable with the noise generated in the grid circuits of the first tube causes saturation of the second limiter. The first limiter is in turn saturated by signals of 1 microvolt, or over.

(*c*) *Discriminator.* The output of the second limiter, free of amplitude variations, is fed through the discriminator transformer T106 to the 7A6 balanced detector (V108). The primary and secondary of the discriminator transformer are coupled both inductively and capacitively. Two voltages of different phase are thus applied to each half of the 7A6. The discriminator is so adjusted that when a steady carrier of 5000 kc is received, the voltage applied to the two halves of the 7A6 cause equal and opposite currents to flow through the load resistors R125 and R126. Thus the resultant voltage appearing across the two resistors is zero.

If any frequency other than 5000 kc appears at the discriminator, the out-of-phase components applied to the 7A6 balanced detector will be unbalanced and a positive or negative resultant voltage will appear across R125 and R126. The sign and magnitude of this voltage will be determined by the frequency of the impressed i-f voltage (different than 5000 kc) rather than by its amplitude variations. In this manner an audio voltage (varying in amplitude) is derived from the frequency variations of the incoming signal. Since the resultant d-c output voltage of the discriminator and detector should be zero when a carrier of the correct frequency is impressed, the secondary of T106 is tuned for zero output with the correct carrier frequency applied. A lead is connected through filter resistors R128 and R129 to the output of the 7A6 so that the current may be metered.

(*d*) *Squelch circuits and audio amplifier.* The audio-frequency output of the discriminator is passed through a voltage-divider network consisting of R128 and R129, where the output of the discriminator is reduced to prevent overloading of the audio amplifier $V110_2$. The audio frequency is then applied to the second grid (G2) of the 7F7. The first triode section of the 7F7 is used to disable (squelch) the second triode section when no carrier is received. The actuating voltages for the squelch circuit are obtained from two sources. One is rectified first limiter grid current and is dependent on signal or noise level. The other is the high-frequency audio component at the output of the discriminator and is dependent only on signal-to-noise ratio.

The negative voltage generated by the first limiter grid current is applied to the 7F7 first triode grid through the isolation resistors R119 and R133. The latter resistor is connected across one diode of V109 (7A6) which acts as a noise trap to eliminate the rectified audio present in the limiter grid circuit. An appropriate time constant in the squelch circuit is effected by capacitors C138B and C159.

The higher audio-frequency components appearing at the discriminator output are selected by C139 and rectified in the other half of V109. A ground return is provided by resistors R131 and R132. Under standby or no-signal conditions, a small negative voltage is applied to the squelch control circuit due to set noise being rectified in the first limiter grid circuit. At the same time the fluctuation noise present in the receiver causes a positive voltage to be generated and applied to the squelch control circuit as shown above. These two voltages tend to balance each other under any noise condition, since an increase or decrease in fluctuation noise will cause like changes in both bucking components. The 7F7 squelch grid (G1) is, then, normally slightly above ground potential. The corresponding cathode of the 7F7 is also positive by virtue of the divider R137 and R141, and R141 is adjusted to just render the squelch half of the 7F7 conducting.

The cathode of the audio portion of the 7F7 is also held positive by a voltage divider R136–R139, but at a considerably higher potential than the squelch cathode. With the squelch portion conducting, a voltage drop will occur through R135, placing the audio grid at a sufficiently negative voltage with respect to its cathode to cause plate current cut-off and blocking of the audio output.

When a signal is received, more negative voltage is generated in the first limiter grid circuit, and at the same time the noise quieting property of the F–M receiver causes less audio noise to be rectified and consequently a less positive voltage applied to the squelch control circuit. These changes are aiding in polarity and cause the potential on the grid of the squelch half of the 7F7 to go in the negative direction and the squelch half of the 7F7 to become non-conducting. With no potential drop through R135 the audio grid assumes the potential existing at the junction of R136, R135 and R139 and the audio section of the tube acts as a normal amplifier. The switch in the cathode circuit of the squelch triode is primarily intended to render the receiver operative during alignment and servicing.

The 7F7 audio amplifier is followed by a 7B5 output pentode with the volume control (R201) in the grid circuit of the output tube and located on the remote control head.

Due to the design of the limiters, the squelch circuits and the audio amplifiers, an excellent degree of noise discrimination is obtained in radio receiver type 1905. The squelch may be set so that a signal of less than one-tenth microvolt will completely open the receiver while noise peaks of very high intensity will not be received.

Resistor R127 and condenser C140 comprise a frequency-correcting network to correct for the high frequency pre-emphasis brought about by phase modulation. Since the deviation is proportional to frequency with phase modulation, the attenuation of the R127–C140 network is made roughly proportional to frequency. The sum of the frequency curves of the transmitter modulator and the receiver audio circuit gives the system audio response listed in Section 18–7.

(*c*) *Power supply.* The vibrator power supply is designed to give economical and trouble-free service. It utilizes a synchronous-type vibrator for maximum efficiency and longest life. Its overall efficiency is high, due to the efficient design of power transformer and power components.

The primary input to the power supply goes through the anti-noise filter E101 to prevent noise voltages from the vibrator from getting back into the primary leads. The primary voltage is applied to the center tap of the primary winding of the power transformer T108. The outer ends of the primary winding are alternately grounded by the vibrator contacts, causing current to flow through the primary first in one direction and then in the other. The alternating currents thus generated set up magnetic fields in the core which in turn induce voltages in the high-voltage secondary winding. Buffer resistors R144 and R145 on the primary, and buffer condenser-resistor C148–R143 on the secondary tend to tune the transformer windings and reduce arcing at the vibrator contacts. The alternating voltage at the transformer secondary is mechanically rectified by a second set of contacts on the vibrator, thus eliminating the need for a separate rectifier tube.

Since the vibrator alternately grounds the opposite ends of the secondary winding in synchronization with the a-c voltage generated therein, the d-c output voltage appears at the secondary center tap. Both ripple and "hash" voltages are present as a-c components of the output voltage. C147 and L104 act as hash filters, while L103, C145A and C145B reduce the ripple voltage to a very low value.

18–7b. Installation—The location of the units in the vehicle has considerable bearing on the subsequent performance, and especially on the accessi-

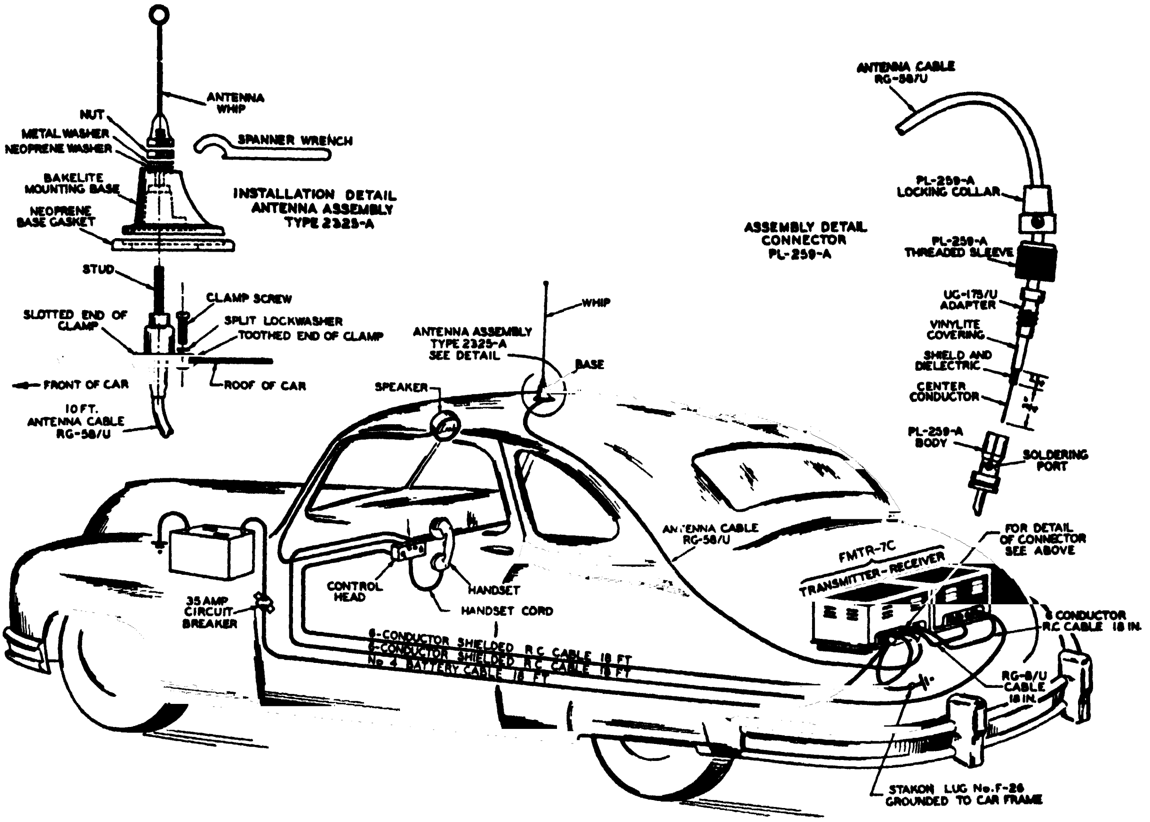

FIG. 18–17. Typical installation of Link type FMTR-7C 152–162-mc radio equipment.

bility and serviceability of the equipment. It should therefore be carefully planned. A typical installation is shown in Figure 18–17. The transmitter and the receiver are mounted side by side on the dual base, with the transmitter on the left and the receiver on the right, since the connecting cables are designed with those relative positions in mind. It may be possible to arrange the transmitter and receiver along the side of the rear compartment, keeping them so that they can be readily removed from their base when desired, and so that all tuning adjustments may be conveniently reached when in place. It is wise in locating the units to try the plug-in cables before installing them permanently to make sure that the chassis are properly located for ready insertion and removal of all plugs.

The control head may be mounted wherever desired, in a location convenient to the operator of the equipment. It was designed for mounting under the edge of the car or truck instrument panel near the center of the vehicle so that either the driver or the person sitting with him could reach it conveniently. A location should be chosen that will permit clear access to the rear of the control head for attaching the necessary cables.

The primary power may be taken, directly from the battery or from some point such as the engine starter, which has a heavy direct connection to the battery already in place. The latter method often makes battery maintenance more convenient by leaving only one heavy lug on each post of the storage battery.

18–7c. Tuning and Operation

1. *Radio Receiver Type 1905.* To turn on the receiver, advance the volume control on the control head in a clockwise direction. The first few degrees of rotation will cause the filament relay in the transmitter to be energized and in turn to energize both the transmitter and receiver filaments. The green receiver pilot lamp on the remote control head will light at the same time. (This light has been purposely made quite dim by means of a dropping resistor because experience has shown a bright pilot to be annoying during continued night driving.)

With the volume control advanced and either squelch switch in the off position, a loud rushing noise should be heard in the loudspeaker, even with the antenna disconnected. If the squelch switches on both the control unit and the receiver chassis are placed in the ON position, all output from the receiver loudspeaker should cease because of the action of the squelch circuit.

The loud noise present in the loudspeaker with either squelch switch off is entirely normal and characteristic of an F–M receiver of adequate sensitivity. Any amount of noise introduced into the receiver or picked up by the antenna will not alter or intensify the characteristic sound of this noise unless a carrier is being received. In the latter case, even a weak signal will greatly reduce or completely suppress the noise.

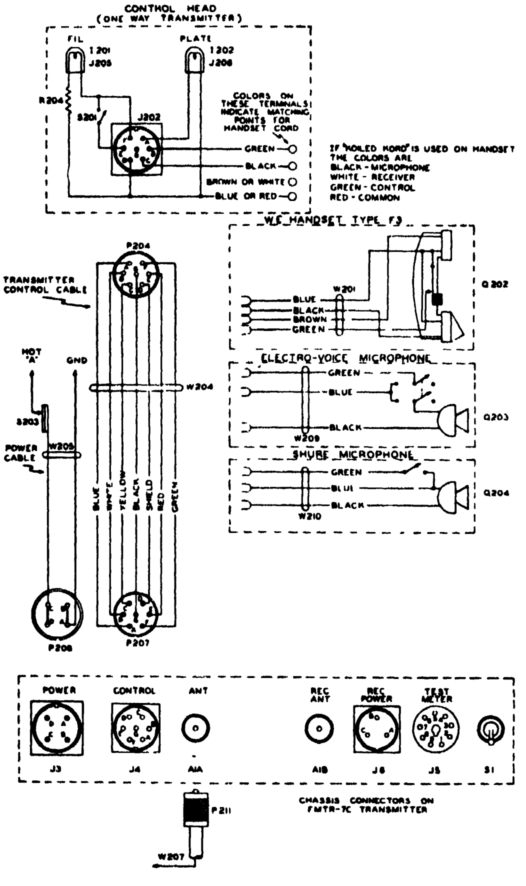

Fig. 18–18. Cable connections, one-way installation of Link radio transmitter type 2240 (or 1906 ed. 2).

When shipped from the factory, the receiver is equipped with the proper tubes and crystal and is tuned approximately to the specified operating frequency. In addition, the approximate positions of the tuning adjustments are marked with red lines to facilitate tuning. For initial tuning, with the antenna connected to the receiver, plug a test meter unit type 2015A into the TEST socket on the front of the receiver, place the meter switch in the 1ST LIM. (500 μa) position and adjust the following for maximum current on the meter while receiving a weak signal on the desired frequency: Condensers C101, C104, C106, C107 and transformers T101, T102, T103, T104, and T109. Tuning must be made on a weak signal so that, on resonance, a deflection of no more than 200 microamperes is obtained on the meter. Next, switch the meter to the 2ND LIM. (500 μa) position, and adjust the tuning controls on T105 for maximum current in the meter. To adjust T106, the secondary is tuned while receiving a signal known to be accurately on frequency. Place the meter switch in the BALANCE (100 μa) position and adjust the tuning capacitor marked BAL. for zero reading on the meter. A completely insulated screwdriver is needed for this adjustment, and the adjustment must be made so that the meter reads zero when the screwdriver is removed. To do this, it will probably be necessary to set the meter a little above or below zero just before the screwdriver is removed. The primary of T106 should then be adjusted for maximum no signal output (rush) as measured by an a-c voltmeter connected between pin F on J103 and ground on the receiver chassis. As a final adjustment the balance of the secondary of T106 should be rechecked while receiving a signal on frequency.

With no signal being received, the discriminator balance should stay within 4 μa of center-zero reading. If it does not, the receiver r-f bandpass is not accurately centered and the tuning procedure should be carefully repeated on a weak signal.

(*a*) *Ignition noise.* Before further adjustments are made, the vehicle should be examined for ignition and other electrical noises such as charging generator brush noise. Mobile radio equipment type FMTR-7C shows a remarkable discrimination against motor-noise and other man-made interferences. In most cases it will be found that no special effort need be made in the vehicle to suppress ignition noise. If it is desired to receive very weak signals, insert the distributor suppressor supplied as close as possible to the distributor. It is assumed that voltage-regulated generators are supplied for maintaining the battery in condition in view of the added battery drain imposed by the radio set. The high charging currents necessary make these units potential sources of interference. In obstinate cases the only cure may be an r-f choke in the main charging lead directly at the generator. An appropriate choke may be made by close winding 10 to 15 turns of No. 8 or larger enameled wire on a form 1 inch to 1½ inches in diameter. Such a choke has a d-c drop of less than 0.1 volt and will not affect a voltage-regulated generator in any way.

After the receiver has been completely tuned and installed in its operating position with ignition and generator noise reduced if necessary, the squelch control may be adjusted. The most sensitive position of this control is completely clockwise. With the adjustment in this position, and the squelch switch ON, advance the volume control and observe the output of the receiver with no signal input. Increase the position of the squelch adjustment in a counterclockwise direction until the output of the receiver is entirely silent. This adjustment should be made with the engine stopped and any normal battery load such as lights, etc., on. It will then hold for most noise conditions, no matter how severe, as a result of the special circuits incorporated in the design of the receiver. Note that in its most sensitive position, the squelch sensitivity is between 0.1 and 0.2 microvolts and that this adjustment will prove sufficient in most cases even where the normal noise level is high.

2. *Radio Transmitter Type 2240 (or 1906 Ed. 2).* When shipped from the factory the transmitter is equipped with the proper tubes and crystal and is tuned correctly to the specified operating frequency. In addition, the approximate positions of the tuning adjustments are marked with red lines to facilitate tuning. For initial tune-up it can be assumed that all the circuits are in proper tune except the PA TUNING and ANTENNA LOADING adjustments. The transmitter may be energized by holding down the push-to-talk button on the handset at the control head, or by closing the test switch on the transmitter chassis.

In order to tune the output circuit of the transmitter, disconnect the antenna cable from the transmitter chassis, place the ANTENNA loading condenser C29 at minimum capacitance (fully counterclockwise), and adjust the PA tuning condenser C26 for minimum cathode current. This current should be approximately 120 ma (or 100 ma). Connect the antenna and re-resonate the PA TUNING adjustment for minimum current. Now increase the antenna tuning capacitance by turning the control in a clockwise direction until the PA cathode current is 185 ma (or 150 ma). These adjustments should be made with the engine running and the car battery under charge.

Do not retune the PA tuning condenser after the loading procedure.

18-8. "Ten Signals"—For several years prior to 1940, the State Police Radio Stations of Iowa, Illinois, Missouri, and Minnesota began to use a number of code signals in their radio transmissions in an effort to speed communication and to cut down the time stations were actually on the air. The Police departments in Wisconsin were quite active in attempting to arrange a uniformity of signals, due to the fact that there was intercommunication between stations and between states.

On March 25, 1940, after a preliminary report on January 3rd, the State Systems Standards Committee of the Association of Police Communication Officers adopted the "Ten Signals" as revised and with meanings carefully selected and proven over the past years use.

A group of those signals that are most generally in use today are reprinted here.

"10" SIGNALS

10-1	Receiving Poorly (cannot understand).
10-2	Receiving Well.
10-3	Stop Transmitting.
10-4	Acknowledgment.
10-5	Relay to.... ....
10-6	Busy (Stand-By).
10-7	Out of Service Until........, or for.......... Minutes.
10-8	In Service.
10-9	Repeat. Conditions Bad.
10-10	Out of Service—Subject to Call.
10-11	Dispatching Too Rapidly.
10-12	Officials or Visitors Present.
10-13	Advise Weather and Road Conditions.
10-14	Convoy or Escort.
10-15	We Have Prisoner in Custody.
10-16	Pick Up Prisoner at.........................
10-17	Pick Up Papers at........................
10-18	Complete Present Assignment as Quickly as Possible.
10-19	Return to Your Station.
10-20	What Is Your Location?
10-21	Call This Station by Telephone.
10-22	Take No Further Action Last Information.
10-23	Stand By Until No Interference to...........
10-25	Do You Have Contact with..................
10-28	Check Full Registration Information (Lic., Motor, Name, Stolen).
10-30	Does Not Conform to Rules and Regulations.
10-33	Emergency Traffic at This Station.
10-34	Clear for Local Dispatch.
10-35	Confidential Information.
10-36	Correct Time.
10-68	Repeat Dispatch.
10-70	Net Message.
10-82	Reserve Room with Bath at Hotel for Officer Nr..
10-83	Have Officer Nr..............call This Station by Telephone.
10-84	Advise Telephone Nr................Your City That Officer Nr................Will Not Return This Date.
10-88	What Fone Number Shall We Call to Make Station to Station Call to....................
10-94	Test. No Talking—Transmitter Only for.....
10-95	Test. Talking for.................
10-99	EMERGENCY—All Stations and Units Copy.

RADIO SIGNALS

1	Contact Hqrs. by telephone.
1-I	Contact Hqrs. by telephone immediately.
2	Contact Hqrs. by Teletype.
2-I	Contact Hqrs. by Teletype immediately.
3	Report to Hqrs. in person.
3-I	Report to Hqrs. in person immediately.
4	Meet complainant and get full report.
5	Investigate vehicle at........................
6	Investigate Occupants of vehicle.
6-I	Investigate occupants driving drunk.
7	Investigate suspicious person.
7-I	Investigate person. Caution-armed.
8	Registration information.
9	Auto accident: Property damage only.
9-I	Auto accident: Personal injury.
9-F	Auto accident: Fatal.
11	Hit and Run: Property damage only.
11-I	Hit and Run: Personal injury.
11-F	Hit and Run: Fatal.

12	Jail break or escape.
13	TROOPER OR OFFICER NEEDS HELP—GO............
13–I	Trouble at Station. Units in vicinity go to Station at once. Use caution.
14	Felony: Investigate.
14–W	Felony: Warrant on file.
14–X	Felony: Warrant and will extradite
15	Unlawful assembly.
15–F	Fight.
15–R	Riot.

Test 199 Yellow Air Raid Test Warning.
Test 299 Blue Air Raid Test Warning.
Test 399 Red Air Raid Test Warning.
Test 499 White Air Raid Test Warning.

Eliminate word Test and the Signals are for actual Air Raid.

CHAPTER 19

IMPORTANT EXTRACTS FROM THE COMMUNICATIONS ACT OF 1934, AS AMENDED BY PUBLIC 97, APPROVED MAY 20, 1937

1. License for Radio Communication or Transmission of Energy—SECTION 301. It is the purpose of this Act, among other things, to maintain the control of the United States over all the channels of interstate and foreign radio transmission; and to provide for the use of such channels, but not the ownership thereof, by persons for limited periods of time, under licenses granted by Federal authority, and no such license shall be construed to create any right, beyond the terms, conditions, and periods of the license. No person shall use or operate any apparatus for the transmission of energy or communications or signals by radio (*a*) from one place in any Territory or possession of the United States or in the District of Columbia to another place in the same Territory, possession, or District; or (*b*) from any State, Territory, or possession of the United States, or from the District of Columbia to any other State, Territory, or possession of the United States; or (*c*) from any place in any State, Territory, or possession of the United States, or in the District of Columbia, to any place in any foreign country or to any vessel; or (*d*) within any State when the effects of such use extend beyond the borders of said State, or when interference is caused by such use or operation with the transmission of such energy, communications, or signals from within said State to any place beyond its borders, or from any place beyond its borders to any place within said State, or with the transmission or reception of such energy, communications, or signals from and/or to places beyond the borders of said State; or (*e*) upon any vessel or aircraft of the United States; or (*f*) upon any other mobile stations within the jurisdiction of the United States, except under and in accordance with this Act and with a license in that behalf granted under the provisions of this Act.

2. Sec. 5—Paragraph (*m*) of section 303 of the Communications Act of 1934 is hereby amended to read as follows:

(*m*) (1) Have authority to suspend the license of any operator upon proof sufficient to satisfy the Commission that the licensee—

(*A*) has violated any provision of any Act, treaty, or convention binding on the United States, which the Commission is authorized to administer, or any regulation made by the Commission under such Act, treaty, or convention; or

(*B*) has failed to carry out a lawful order of the master or person lawfully in charge of the ship or aircraft on which he is employed; or

(*C*) has willfully damaged or permitted radio apparatus or installations to be damaged; or

(*D*) has transmitted superfluous radio communications or signals or communications containing profane or obscene words, language, or meaning, or has knowingly transmitted—

(1) false or deceptive signals or communications, or

(2) a call signal or letter which has not been assigned by proper authority to the station he is operating; or

(*E*) has willfully or maliciously interfered with any other radio communications or signals; or

(*F*) has obtained or attempted to obtain, or has assisted another to obtain or attempt to obtain, an operator's license by fraudulent means.

(2) No order of suspension of any operator's license shall take effect until fifteen days' notice in writing thereof, stating the cause for the proposed suspension, has been given to the operator licensee who may make written application to the Commission at any time within said fifteen days for a hearing upon such order. The notice to the operator licensee shall not be effective until actually received by him, and from that time he shall have fifteen days in which to mail the said application. In the event that physical conditions prevent mailing of the application at the expiration of the fifteen-day period, the application shall then be mailed as soon as possible thereafter, accompanied by a satisfactory explanation of the delay. Upon receipt by the Commission of such application for hearing, said order of suspension shall be held in abeyance until the conclusion of the hearing which shall be conducted under such rules as the Commission may prescribe. Upon the conclusion of said hearing the Commission may affirm, modify, or revoke said order of suspension.

3. Facilities for Candidates for Public Office—SEC. 315. If any licensee shall permit any person who is a legally qualified candidate for any public office to use a broadcasting station, he shall afford equal opportunities to all other such candidates for that office in the use of such broadcasting station, and the Commission shall make rules and regulations to carry this provision into effect: *Provided,* That such licensee shall have no power of censorship over the material broadcast under the provisions of this section. No obligation is hereby imposed upon any licensee to allow the use of its station by any such candidate.

4. Lotteries and Other Similar Schemes—Sec. 316. No person shall broadcast by means of any radio station for which a license is required by any law of the United States, and no person operating any such station shall knowingly permit the broadcasting of, any advertisement of or information concerning any lottery, gift enterprise, or similar scheme, offering prizes dependent in whole or in part upon lot or chance, or any list of the prizes drawn or awarded by means of any such lottery, gift enterprise, or scheme, whether said list contains any part or all of such prizes. Any person violating any provision of this section shall, upon conviction thereof, be fined not more than $1,000 or imprisoned not more than one year, or both, for each and every day during which such offense occurs.

5. Announcement that Matter is Paid for—Sec. 317. All matter broadcast by any radio station for which service, money, or any other valuable consideration is directly or indirectly paid, or promised to or charged or accepted by, the station so broadcasting, from any person, shall, at the time the same is so broadcast, be announced as paid for or furnished, as the case may be, by such person.

6. Licensed Operator—Sec. 318. The actual operation of all transmitting apparatus in any radio station for which a station license is required by this Act shall be carried on only by a person holding an operator's license issued hereunder, and no person shall operate any such apparatus in such station except under and in accordance with an operator's license issued to him by the Commission: Provided, however, That the Commission if it shall find that the public interest, convenience or necessity will be served thereby may waive or modify the foregoing provisions of this section for the operation of any station except (1) stations for which licensed operators are required by international agreement, (2) stations for which licensed operators are required for safety purposes, (3) stations engaged in broadcasting, and (4) stations operated as common carriers on frequencies below thirty thousand kilocycles: Provided further, That the Commission shall have power to make special regulations governing the granting of licenses for the use of automatic radio devices and for the operation of such devices.

7. Designation of Stations Liable to Interfere with Distress Signals—Sec. 320. The Commission is authorized to designate from time to time radio stations the communications or signals of which, in its opinion, are liable to interfere with the transmission or reception of distress signals of ships. Such stations are required to keep a licensed radio operator listening in on the frequencies designated for signals of distress and radio communications relating thereto during the entire period the transmitter of such station is in operation.

8. Ship Transmitter Adjustment—Sec. 321. (*a*) The transmitting set in a radio station on shipboard may be adjusted in such a manner as to produce a maximum of radiation, irrespective of the amount of interference which may thus be caused, when such station is sending radio communications or signals of distress and radio communications relating thereto.

(b) All radio stations, including Government stations and stations on board foreign vessels when within the territorial waters of the United States, shall give absolute priority to radio communications or signals relating to ships in distress; shall cease all sending on frequencies which will interfere with hearing a radio communication or signal of distress, and, except when engaged in answering or aiding the ship in distress, shall refrain from sending any radio communications or signals until there is assurance that no interference will be caused with the radio communications or signals, relating thereto, and shall assist the vessel in distress, so far as possible, by complying with its instructions.

9. Exchange of Messages and Signals—Sec. 322. Every land station open to general public service between the coast and vessels or aircraft at sea shall, within the scope of its normal operations, be bound to exchange radio communications or signals with any ship or aircraft station at sea; and each station on shipboard or aircraft at sea shall, within the scope of its normal operations, be bound to exchange radio communications or signals with any other station on shipboard or aircraft at sea or with any land station open to general public service between the coast and vessels or aircraft at sea: Provided, That such exchange of radio communication shall be without distinction as to radio systems or instruments adopted by each station.

10. Interference between Government and Commercial Stations—Sec. 323. (*a*) At all places where Government and private or commercial radio stations on land operate in such close proximity that interference with the work of Government stations cannot be avoided when they are operating simultaneously, such private or commercial stations as do interfere with the transmission or reception of radio communications or signals by the Government stations concerned shall not used their transmitters during the first fifteen minutes of each hour, local standard time.

(*b*) The Government stations for which the above-mentioned division of time is established shall transmit radio communications or signals only during the first fifteen minutes of each hour, local standard time, except in case of signals or radio communications relating to vessels in distress and vessel requests for information as to course, location, or compass direction.

11. Use of Minimum Power.—SEC. 324. In all circumstances, except in case of radio communications or signals relating to vessels in distress, all radio stations, including those owned and operated by the United States, shall use the minimum amount of power necessary to carry out the communication desired.

12. False Distress Signals; Rebroadcasting; Studios of Foreign Stations—SEC. 325. (*a*) No person within the jurisdiction of the United States shall knowingly utter or transmit, or cause to be uttered or transmitted, any false or fraudulent signal of distress, or communication relating thereto, nor shall any broadcasting station rebroadcast the program or any part thereof of another broadcasting station without the express authority of the originating station.

(*b*) No person shall be permitted to locate, use, or maintain a radio broadcast studio or other place or apparatus from which or whereby sound waves are converted into electrical energy, or mechanical or physical reproduction of sound waves produced, and caused to be transmitted or delivered to a radio station in a foreign country for the purpose of being broadcast from any radio station there having a power output of sufficient intensity and/or being so located geographically that its emissions may be received consistently in the United States, without first obtaining a permit from the Commission upon proper application therefor.

(*c*) Such application shall contain such information as the Commission may by regulation prescribe, and the granting or refusal thereof shall be subject to the requirements of section 309 hereof with respect to applications for station licenses or renewal or modification thereof, and the license or permission so granted shall be revocable for false statements in the application so required or when the Commission, after hearings, shall find its continuation no longer in the public interest.

13. Censorship; Indecent Language—SEC. 326. Nothing in this Act shall be understood or construed to give the Commission the power of censorship over the radio communications or signals transmitted by any radio station, and no regulation or condition shall be promulgated or fixed by the Commission which shall interfere with the right of free speech, by means of radio communication. No person within the jurisdiction of the United States shall utter any obscene, indecent, or profane language by means of radio communication.

TITLE III—PROVISIONS RELATING TO RADIO

PART I—GENERAL PROVISIONS

(*b*) Such title III is further amended by adding at the end thereof a new part as follows:

PART II—*Radio Equipment and Radio Operators on Board Ship*

Ship Radio Installations and Operations

14. Ships Subject to Amended Act—SEC. 351. (*a*) Except as provided in section 352 hereof, it shall be unlawful—

(1) For any ship of the United States, other than a cargo ship of less than sixteen hundred gross tons, to be navigated in the open sea outside of a harbor or port, or for any ship of the United States or any foreign country, other than a cargo ship of less than sixteen hundred gross tons, to leave or attempt to leave any harbor or port of the United States for a voyage in the open sea, unless such ship is equipped with an efficient radio installation in operating condition, in charge of and operated by a qualified operator or operators, adequately installed and protected so as to insure proper operation, and so as not to endanger the ship and radio installation, as hereinafter provided, and in the case of a ship of the United States, unless there is on board a valid station license issued in accordance with this Act;

(2) For any passenger ship of the United States of five thousand gross tons, or over, to be navigated outside of a harbor or port, in the open sea, or for any such ship of the United States or any foreign county to leave or attempt to leave any harbor or port of the United States for a voyage in the open sea, unless such ship is equipped with an efficient radio direction finder apparatus (radio compass) properly adjusted in operating condition as hereinafter provided, which apparatus is approved by the Commission;

(*b*) A ship which is not subject to the provisions of this part at the time of its departure on a voyage shall not become subject to such provisions on account of any deviation from its intended voyage due to stress of weather or any other cause over which neither the master, the owner, nor the charterer (if any) has control.

15. Exceptions—SEC. 352. (*a*) The provisions of this part shall not apply to—

(1) A ship of war;

(2) A ship of the United States belonging to and operated by the Government, except a ship of the United States Maritime Commission, the Inland and Coastwise Waterways Service, or the Panama Railroad Company;

(3) A foreign ship belonging to a country which is a party to the Safety Convention and which ship carries a valid certificate exempting said ship from the radio provisions of that Convention, or which ship conforms to the radio requirements of such Convention or Regulations and has on board a valid certificate to that effect;

(4) Yachts of less than six hundred gross tons not subject to the radio provisions of the Safety Convention;

(5) Vessels in tow;

(6) A vessel navigating solely on the Great Lakes, or on any bays, sounds, rivers, or protected waters within the jurisdiction of the United States, or to a vessel leaving or attempting to leave any harbor or port of the United States for a voyage solely on the Great Lakes, or on any bays, sounds, rivers, or protected waters within the jurisdiction of the United States.

(*b*) The Commission may, if it considers that the route or the conditions of the voyage or other circumstances are such as to render a radio installation unreasonable or unnecessary for the purposes of this part, exempt from the provisions of this part any ship, or any class of ships, which falls within any of the following descriptions:

(1) Passenger ships which in the course of their voyage do not go more than twenty nautical miles from the nearest land or more than two hundred nautical miles between two consecutive ports;

(2) Cargo ships which in the course of their voyage do not go more than one hundred and fifty nautical miles from the nearest land;

(3) Passenger vessels of less than one hundred gross tons not subject to the radio provisions of the Safety Convention;

(4) Sailing ships.

16. Operators, Watches, Auto-Alarm—Sec. 353. (*a*) Each cargo ship required by this part to be fitted with a radio installation and which is not fitted with an auto-alarm, and each passenger ship required by this part to be fitted with a radio installation, shall, for safety purposes, carry at least two qualified operators.

(*b*) A cargo ship, required by this part to be fitted with a radio installation, which is fitted with an auto-alarm in accordance with this title, shall, for safety purposes, carry at least one qualified operator who shall have had at least six months' previous service in the aggregate as a qualified operator in a station on board a ship or ships of the United States.

(*c*) Each ship of the United States required by this part to be fitted with a radio installation shall, while being navigated outside a harbor or port, keep a continuous watch by means of qualified operators: Provided, however, That in lieu thereof on a cargo ship fitted with an auto-alarm in proper operating condition, a watch of at least eight hours per day, in the aggregate, shall be maintained by means of a qualified operator.

(*d*) The Commission shall, when it finds it necessary for safety purposes, have authority to prescribe the particular hours of watch on a ship of the United States required by this part to be fitted with a radio installation.

(*e*) On all ships of the United States fitted with an auto-alarm, said apparatus shall be in operation at all times while the ship is being navigated outside of a harbor or port when the operator is not on watch.

17. Technical Requirements—Sec. 354. The radio installation and the radio direction-finding apparatus required by section 351 of this part shall comply with the following requirements:

(*a*) The radio installation shall comprise a main and an emergency or reserve installation: Provided, however, That on a cargo ship, if the main installation complies also with all the requirements of an emergency or reserve installation, the emergency or reserve installation may be omitted.

(*b*) The ship's radio operating room and the emergency or reserve installation shall be placed in the upper part of the ship in a position of the greatest possible safety and as high as practicable above the deepest load water line, and the location of such room or rooms shall be approved by the Bureau of Marine Inspection and Navigation, Department of Commerce.

(*c*) The main and emergency or reserve installations shall be capable of transmitting and receiving on the frequencies and types of waves designated by the Commission pursuant to law for the purpose of distress and safety of navigation.

(*d*) The main installation shall have a normal transmitting and receiving range of at least two hundred nautical miles, that is to say, it must be capable of transmitting and receiving clearly perceptible signals from ship to ship over a range of at least two hundred nautical miles by day under normal conditions and circumstances.

(*e*) Sufficient power shall be available at all times to operate the main radio installation efficiently under normal conditions over the range specified in subsection (*d*) of this section.

(*f*) The emergency or reserve installation shall include a source of energy independent of the propelling power of the ship and of any electrical system and shall be capable of being put into operation rapidly and of working for at least six continuous hours. For the emergency or reserve installation, the normal range as defined in subsection (*d*) of this section shall be at least one hundred nautical miles.

(*g*) There shall be provided between the bridge of the ship and the radio room, and between the bridge and the location of the direction finding apparatus, when the direction finding apparatus is not located on the bridge, an efficient means of communication independent of any other communication system of the ship.

(*h*) The direction finding apparatus shall be efficient and capable of receiving clearly perceptible radio signals and of taking bearings from which the true bearing and direction may be determined. It shall be capable of receiving signals on the frequencies prescribed for distress, direction finding, and radio beacons by the General Radio Regulations annexed to the International Telecommunication Convention in force and in new installations after the effective date of this part, such other frequencies as the Commission may for safety purposes designate.

18. Lifeboats—SEC. 355. Every motor lifeboat, required to be equipped with radio by treaty or convention to which the United States is a party, by statute, or by regulation made in conformity with a treaty, convention, or statute, shall be fitted with an efficient radio installation under such rules and regulations as the Commission may find necessary to promote the safety of life.

19. Approval of Installation—SEC. 356. (*a*) Insofar as is necessary to carry out the purposes and requirements of this part, the Commission shall have authority, for any ship subject to this part—

(1) To approve the details as to the location and manner of installations of the equipment required by this part or of equipment necessitated by reason of the purposes and requirements of this part.

(2) To approve installations, apparatus, and spare parts necessary to comply with the purposes and requirements of this part.

(3) To prescribe such additional equipment as may be determined to be necessary to supplement that specified herein, for the proper function of the radio installation installed in accordance with this part or for the proper conduct of radio communication in time of emergency or distress.

20. Transmission of Information—SEC. 357. (*a*) The master of every ship of the United States equipped with radio transmitting apparatus, on meeting with dangerous ice, a dangerous derelict, a tropical storm, or any other direct danger to navigation, shall cause to be transmitted all pertinent information relating thereto, to ships in the vicinity and to the appropriate authorities, in accordance with rules and regulations issued by the Commission, which authorities of the United States shall, when they consider it necessary, promptly bring the information received by them to the knowledge of those concerned and foreign authorities interested.

(*b*) No charge shall be made by any ship or station in the mobile service of the United States for the transmission, receipt, or relay of the information designated in subsection (*a*) originating on a ship of the United States or of a foreign country.

(*c*) The transmission by any ship of the United States, made in compliance with subsection (*a*), to any station which imposes a charge for the reception, relay, or forwarding of the required information, shall be free of cost to the ship concerned and any communication charges incurred by the ship for transmission, relay, or forwarding of the information may be certified to the Commission for reimbursement out of moneys appropriated to the Commission for that purpose.

(*d*) No charge shall be made by any ship or station in the mobile service of the United States for the transmission of distress messages and replies thereto in connection with situations involving the safety of life and property at sea.

(*e*) Notwithstanding any other provision of law, any station or carrier may render free service in connection with situations involving the safety of life and property, including hydrographic reports, weather reports, reports regarding aids to navigation and medical assistance to injured or sick persons on ships and aircraft at sea. All free service permitted by this subsection shall be subject to such rules and regulations as the Commission may prescribe, which rules may limit such free service to the extent which the Commission finds desirable in the public interest.

21. Authority of Master—SEC. 358. The radio installation, the operators, the regulation of their watches, the transmission and receipt of messages, and the radio service of the ship except as they may be regulated by law or international agreement, or by rules and regulations made in pursuance thereof, shall in the case of a ship of the United States be under the supreme control of the master.

22. Certificates—SEC. 359. (*a*) Each vessel of the United States to which the Safety Convention applies shall comply with the Radio and communication provisions of said convention at all times while the vessel is in use, in addition to all other requirements of law, and have on board an appropriate certificate as prescribed by the Safety Convention.

(*b*) Appropriate certificates concerning the radio particulars provided for in said convention shall be issued to any vessel of the United States which is subject to the radio provisions of the Safety Convention and is found by the Commission to comply therewith. Such certificates shall be issued by the Department of Commerce, or whatever other agency is authorized by law so to do, upon request of the Commission made after proper inspection or determination of the facts. If the holder of such certificate violates the provisions of the safety convention, or of this Act, or the rules, regulations, or conditions prescribed by the Commission, and if the effective administration of the safety convention or of this part so requires, the Commission, after hearing in accordance with law, is authorized to request the modification or cancelation of such certificate. Upon receipt of such request the Department of Commerce, or whatever other agency is authorized by law to do so, shall modify or cancel the certificate in accord therewith. The Commission is authorized to issue, modify, or cancel such certificates in the event that no other agency is authorized to do so.

23. Inspections—Sec. 360. (*a*) In addition to any other provisions required to be included in a radio station license, the station license of each ship of the United States subject to this title shall include particulars with reference to the items specifically required by this title.

(*b*) Every ship of the United States, subject to this part, shall have the equipment and apparatus prescribed therein, inspected at least once each year by the Commission. If, after such inspection, the Commission is satisfied that all relevant provisions of this Act and the station license have been complied with, that fact shall be certified to on the station license by the Commission. The Commission shall make such additional inspections at frequent intervals as may be necessary to insure compliance with the requirements of this Act.

24. Control by Commission—Sec. 361. Nothing in this title shall be interpreted as lessening in any degree the control of the Commission over all matters connected with the radio equipment and its operation on shipboard and its decision and determination in regard to the radio requirements, installations, or exemptions from prescribed radio requirements shall be final, subject only to review in accordance with law.

25. Forfeitures—Sec. 362. The following forfeitures shall apply to this part, in addition to the penalties and forfeitures provided by title V of this Act:

(*a*) Any ship that leaves or attempts to leave any harbor or port of the United States in violation of the provisions of this part, or the rules and regulations of the Commission made in pursuance thereof, or any ship of the United States that is navigated outside of any harbor or port in violation of any of the provisions of this part, or the rules and regulations of the Commission made in pursuance thereof, shall forfeit to the United States the sum of $500, recoverable by way of suit or libel. Each such departure or attempted departure, and in the case of a ship of the United States each day during which such navigation occurs shall constitute a separate offense.

(*b*) Every willful failure on the part of the master of a ship of the United States to enforce or to comply with the provisions of this Act or the rules and regulations of the Commission as to equipment, operators, watches, or radio service shall cause him to forfeit to the United States the sum of $100.

26. General Penalty—Sec. 501. Any person who willfully and knowingly does or causes or suffers to be done any act, matter, or thing, in this Act prohibited or declared to be unlawful, or who willfully and knowingly omits or fails to do any act, matter, or thing in this Act required to be done, or willfully and knowingly causes or suffers such omission or failure, shall, upon conviction thereof, be punished for such offense, for which no penalty (other than a forfeiture) is provided herein, by a fine of not more than $10,000 or by imprisonment for a term of not more than two years, or both.

27. Violations of Rules, Regulations—Sec. 502. Any person who willfully and knowingly violates any rule, regulation, restriction or condition made or imposed by the Commission under authority of this Act, or any rule, regulation, restriction, or condition made or imposed by any international radio or wire communications treaty or convention, or regulations annexed thereto, to which the United States is or may hereafter become a party, shall, in addition to any other penalties provided by law, be punished, upon conviction thereof, by a fine of not more than $500 for each and every day during which such offense occurs.

28. Ship Act—Section 602 of the Communications Act of 1934 is hereby amended by adding at the end thereof a new subsection to read as follows:

(*e*) Such part or parts of the Act entitled "An Act to require apparatus and operators for radio communication on certain ocean steamers," approved June 24, 1910, as amended, as relate to the ocean and to steamers navigating thereon, are hereby repealed. In all other respects said Act shall continue in full force and effect. The Commission is requested and directed to make a special study of the radio requirements necessary or desirable for safety purposes for ship navigating the Great Lakes and the inland waters of the United States, and to report its recommendations, and the reasons therefor, to the Congress not later than December 31, 1939.

29. Unauthorized Publication of Communications—Sec. 605. No person receiving or assisting in receiving, or transmitting, or assisting in transmitting, any interstate or foreign communication by wire or radio shall divulge or publish the existence, contents, substance, purport, effect, or meaning thereof, except through authorized channels of transmission or reception, to any person other than the addressee, his agent, or attorney, or to a person employed or authorized to forward such communication to its destination, or to proper accounting or distributing officers of the various communicating centers over which the communication may be passed, or to the master of a ship under whom he is serving, or in response to a subpoena issued by a court of competent jurisdiction, or on demand of other lawful authority; and no person not being authorized by the sender shall intercept any communication and divulge or publish the existence, contents, substance, purport, effect, or meaning of such intercepted communication to any person; and no person not being entitled thereto shall receive or assist in receiving any interstate or foreign communication by wire or radio and use the same or any information therein contained for his own benefit or for the benefit of another not entitled thereto; and no person having received such intercepted communication or having become acquainted with the contents, substance, purport, effect, or meaning of the same or any part thereof, knowing that such information was so obtained, shall divulge or publish the existence, contents, substance, purport, effect, or meaning of the same or any part thereof, or use the same or any information therein contained for his own benefit or for the benefit of another not entitled thereto: *Provided*, That this section shall not apply to the receiving, divulging, publishing, or utilizing the contents of any radio communication broadcast, or transmitted by amateurs or others for the use of the general public, or relating to ships in distress.

30. Short Title—Sec. 609. This Act may be cited as the "Communications Act of 1934."

Approved June 19, 1934.

CHAPTER 20

F.C.C. RULES AND REGULATIONS

PREFACE TO THE RULES AND REGULATIONS OF THE FEDERAL COMMUNICATIONS COMMISSION

The "Rules and Regulations of the Federal Communications Commission" incorporate all the rules and regulations of a general or permanent nature in force as of the effective date appearing at the beginning of each part. The title, "Title 47—Telecommunication," has been adopted for all the rules to correspond with the codification thereof under the provisions of the Federal Register Act, and also to correspond with the title under which the Communications Act is printed in the United States Code.

In preparing this compilation, the Commission has had in mind the necessity for an arrangement which would make the rules conveniently accessible and one which would also make provision for future amendments. To this end all the existing rules have been logically arranged under 33 parts, which have been suitably subdivided, employing nonconsecutive part numbers from 1 to 65, making provision for substitutions and additions.

The various parts are independently numbered, each part beginning with the principal section number allocated for the purpose and in keeping with the system of numbering which has been used, and these section numbers run consecutively only within the part. The first section of each part begins with ".1." Gaps are left in the numbering throughout so that new and amendatory provisions may be inserted with due regard to their relation to the compilation as a whole.

Each part has been printed and bound in separate pamphlet form, and each contains a title page listing the part numbers and titles of all the Rules and Regulations. In addition, explanatory footnotes have been included referring to statutes or treaties applicable to particular services and, so far as practicable, to other applicable parts.

It is intended that future amendments will be made available in such form that the substitute or added pages may be readily inserted within the part.

Provisions of the rules may be cited thus: "Section or § 8.1 Federal Communications Commission Rules."

Copies of these rules may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C.

RULES OF PRACTICE AND PROCEDURE

§ 1.401 **Notice of violations.**—Any licensee who appears to have violated any provision of the Communications Act of 1934 or of the rules and regulations of the Federal Communications Commission, shall be served with a notice calling the facts to his attention and requesting a statement concerning the matter. Within 3 days from receipt of such notice, or such other period as may be specified, the licensee shall send a written answer direct to the office of the Commission originating the official notice. If an answer cannot be sent nor an acknowledgment made within such 3-day period by reason of illness or other unavoidable circumstances, acknowledgment and answers shall be made at the earliest practicable date with a satisfactory explanation of the delay. The answer to each notice shall be complete in itself and shall not be abbreviated by reference to other communications or answers to other notices. If the notice relates to violations that may be due to the physical or electrical characteristics of transmitting apparatus, the answer shall state fully what steps, if any, have been taken to prevent future violations, and if any new apparatus is to be installed, the date such apparatus was ordered, the name of the manufacturer, and promised date of delivery. If the installation of such apparatus requires a construction permit, the file number of the application shall be given, or if a file number has not been assigned by the Commission such identification shall be given as will permit ready identification thereof. If the notice of violation relates to lack of attention to or improper operation of the transmitter, the name and license number of the operator in charge shall be given.

§ 1.404 **Suspension of operator licenses.**—Whenever it appears that grounds exist for suspension of an operator license, as provided in section 303 (m) of the act, the Bureau of Law after conferring with the other Bureaus of the Commission prepares a report and other necessary papers which are presented to the Commission for action. If the Commission concludes that suspension proceedings should be instituted, a suspension order will be issued. No order of suspension of any operator's license shall take effect until 15 days' notice in writing thereof, stating the cause for the proposed suspension, has been given to the operator licensee who may make written application to the Commission at any time within said 15 days for a hearing upon such order. The notice to the operator licenses shall not be effective until actually received by him, and from that time he shall have 15 days in which to mail the said application. In the event that physical conditions prevent mailing of the application before the expiration of the 15-day period, the application shall then be mailed as soon as possible thereafter, accompanied by a satisfactory explanation of the delay. Upon receipt by the Commission of such application for hearing, said order of suspension shall be held in abeyance until the conclusion of the hearing which shall be conducted under such rules as the Commission shall deem appropriate. Upon the conclusion of said hearing the Commission may affirm, modify, or revoke said order of suspension. If the license is ordered suspended, the operator shall send his operator license to the office of the Commission in Washington, D. C., on or before the effective date of the order, or, if the effective date has passed at the time notice is received, the license shall be sent to the Commission forthwith.

GENERAL RULES AND REGULATIONS

§ 2.102 **Nomenclature of frequencies.**—Frequencies shall be expressed in kilocycles per second (kc) at and below 30,000 kilocycles per second and in megacycles per second (Mc) above this frequency.

Frequency Subdivision	*Frequency Range*
VLF (very low frequency)	Below 30 kc.
LF (low frequency)	30 to 300 kc.
MF (medium frequency)	300 to 3000 kc.
HF (high frequency)	3000 to 30,000 kc.
VHF (very high frequency)	30,000 to 300 Mc.
UHF (ultra high frequency)	300 Mc. to 3000 Mc.
SHF (super high frequency)	3000 Mc. to 30,000 Mc.
EHF (extremely high frequency)	30,000 Mc. to 300,000 Mc.

SUBPART C—EMISSIONS

§ 2.201 **Emission, modulation and transmission characteristics.**—The following system of designating emission, modulations and transmission characteristics shall be employed.

(*a*) The emission characters used in connection with frequency assignments express:

(1) Necessary bandwidth.
(2) Type of modulation or emission.
(3) Type of transmission.
(4) Supplementary characteristics authorized.

(*b*) Types of modulation and emission are symbolized according to the following letters:

(1) Amplitude modulation	A
(2) Frequency (or phase) modulation	F
(3) Pulsed emission	P

(*c*) Types of transmission are symbolized according to the following numbers:

(1) Absence of any modulation intended to carry information	0
(2) Telegraphy without the use of modulating audio frequency	1
(3) Telegraphy by the keying of a modulating audio frequency or audio frequencies or by the keying of the modulated emission (special case: an unkeyed modulated emission)	2
(4) Telephony	3
(5) Facsimile	4
(6) Television	5
(7) Composite transmissions and cases not covered by the above	9

(*d*) Supplementary characteristics are symbolized in accordance with the following letters:

(1) Double sideband, full carrier	(None)
(2) Single sideband, reduced carrier	a
(3) Two independent sidebands, reduced carrier	b
(4) Other emissions, reduced carrier	c
(5) Pulse, amplitude modulated	d
(6) Pulse, width modulated	e
(7) Pulse, phase (or position) modulated	f

(*e*) The classification of emissions is tabulated on page 792.

(*f*) *Type B emission.*—As an exception to the above principles, damped waves are symbolized in the Commission's rules and regulations as type B emission.

SUBPART D—IDENTIFICATION OF RADIO COMMUNICATION AND ALLOCATION AND USE OF CALL SIGNS

§ 2.301 **Identification of transmissions.**—For the purpose of identifications, with a view to the elimination of harmful interference and the general enforcement of applicable radio treaties, conventions, regulations, arrangements and agreements in force, and the enforcement of the Communications Act of 1934, as amended, and the Commission's rules, each station using radio frequencies shall identify its transmissions as prescribed by the rules governing such classes of stations.

SUBPART E—DISTRESS, DISASTER AND EMERGENCY COMMUNICATIONS

§ 2.401 **Distress messages.**—Each station licensee shall give absolute priority to radiocommunications or signals relating to ships or aircraft in distress; shall cease all sending on frequencies which will interfere with hearing a radiocommunication or signal of distress and except when engaged in answering or aiding the ship or aircraft in distress, shall refrain from sending any radiocommunications or signals until there is assurance that no interference will be caused with the radiocommunications or signals relating thereto; and shall assist the ship or aircraft in distress, so far as possible, by complying with its instructions.

§ 2.402 **Control of distress traffic.**—The control of distress traffic is the responsibility of the mobile station in distress or of the mobile station

Type of Modulation or Emission	Type of Transmission	Supplementary Characteristics	Symbol
1. Amplitude	Absence of any modulation		A0
	Telegraphy without the use of modulating audio frequency (on-off keying).		A1
	Telegraphy by the keying of a modulating audio frequency or audio frequencies or by the keying of the modulated emission (special case; an unkeyed modulated emission).		A2
	Telephony	Double sideband, full carrier	A3
		Single sideband, reduced carrier.	A3a
		Two independent sidebands, reduced carrier.	A3b
	Facsimile		A4
	Television		A5
	Composite transmissions and cases not covered by the above.		A9
	Composite transmissions	Reduced carrier	A9c
2. Frequency (or phase) modulated.	Absence of any modulation		F0
	Telegraphy without the use of modulating audio frequency (frequency shift keying).		F1
	Telegraphy by the keying of a modulating audio frequency or audio frequencies or by the keying of the modulated emission (special case: an unkeyed emission modulated by audio frequency).		F2
	Telephony		F3
	Facsimile		F4
	Television		F5
	Composite transmissions and cases not covered by the above.		F9
3. Pulsed emissions	Absence of any modulation intended to carry information.		P0
	Telegraphy without the use of modulating audio frequency.		P1
	Telegraphy by the keying of a modulating audio frequency or audio frequencies, or by the keying of the modulated pulse (special case: an unkeyed modulated pulse).	Audio frequency or audio frequencies modulating their pulse in amplitude.	P2d
		Audio frequency or audio frequencies modulating the width of the pulse.	P2e
		Audio frequency or audio frequencies modulating the phase (or position) of the pulse.	P2f
	Telephony	Amplitude modulated pulse	P3d
		Width modulated pulse	P3e
		Phase (or position) modulated pulse.	P3f
	Composite transmissions and cases not covered by the above.		P9

which, by the application of the provisions of § 2.403, has sent the distress call. These stations may, however, delegate the control of the distress traffic to another station.

§ 2.403 **Retransmission of distress message.**—Any station which becomes aware that a mobile station is in distress may transmit the distress message in the following cases:

(*a*) When the station in distress is not itself in a position to transmit the message.

(*b*) In the case of mobile stations, when the master or the person in charge of the ship, aircraft, or other vehicles carrying this station which intervenes believes that further help is necessary.

(*c*) In the case of other stations, when directed to do so by the station in control of distress traffic or when it has reason to believe that a distress call which it has intercepted has not been received by any station in a position to render aid.

§ 2.404 **Resumption of operation after distress.**—No station having been notified to cease operation shall resume operation on frequency or frequencies which may cause interference until notified by the station issuing the original notice that the station involved will not interfere with distress traffic as it is then being routed or until the receipt of a general notice that the need for handling distress traffic no longer exists.

§ 2.405 **Communications in emergencies.**—The licensee of any station, except amateur, may, during a period of emergency in which normal communication facilities are disrupted as a result of hurricane, flood, earthquake, or similar disaster, utilize such station for emergency communication service in communicating in a manner other than that specified in the instrument of authorization, provided:

(*a*) That as soon as possible after the beginning of such emergency use, notice be sent to the Commission at Washington, D. C., and to the Engineer in Charge of the district in which the station is located, stating the nature of the emergency and the use to which the station is being put, and

(*b*) That the emergency use of the station shall be discontinued as soon as substantially normal communication facilities are again available, and

(*c*) That the Commission at Washington, D. C. and the Engineer in Charge shall be notified immediately when such special use of the station is terminated; provided further,

(*d*) That in no event shall any station engage in emergency transmission on frequencies other than, or with power in excess of, that specified in the instrument of authorization or as otherwise expressly provided by the Commission, or by law, and provided further,

(*e*) That the Commission may, at any time, order the discontinuance of any such emergency communication undertaken under this section.

RULES GOVERNING COMMERCIAL RADIO OPERATORS

GENERAL

§ 13.1 **Licensed operators required.**[1, 2, 3]—Unless otherwise specified by the Commission, the actual operation of any radio station for which a station license is required shall be carried on only by a licensed radio operator of the required class.[4]

§ 13.2 **Classes of licenses.**[5]—The classes of commercial operator licenses issued by the Commission are:

(*a*) Commercial radiotelephone group:

(1) Radiotelephone second-class operator license.

(2) Radiotelephone first-class operator license.

(*b*) Commercial radiotelegraph group:

(1) Radiotelegraph second-class operator license.

(2) Radiotelegraph first-class operator license.

(*c*) Restricted commercial group:

(1) Restricted radiotelephone operator permit.

(2) Restricted radiotelegraph operator permit.

§ 13.3 **Dual holding of licenses.**—A person may not hold more than one radiotelegraph operator license (or restricted radiotelegraph permit) and one radiotelephone operator license (or restricted radiotelephone operator permit) at the same time.

§ 13.4 **Term of licenses.**—Commercial operator licenses are normally issued for a term of 5 years from the date of issuance.

§ 13.5 **Eligibility for new license.**—(*a*) Under the provisions of Section 303(1) of the Communications Act of 1934, as amended, United States citizens who are found qualified by the Commission are the only persons to whom radio operator licenses may be issued.

(*b*) Notwithstanding any other provisions of the Commission's Rules, no person otherwise eligible shall be deemed to be eligible to be examined for or to receive a commercial radio operator license of any class, (1) whose commercial radio operator license is under suspension or is involved in a suspension proceeding, or (2) who is involved in any pending litigation based on an alleged violation of the Communications Act of 1934, as amended.

§ 13.6 **Operator license, posting of.**—The original license of each station operator shall be posted at the place where he is on duty, except as otherwise provided in this Part of the rules or in the rules governing the class of station concerned.

§ 13.7 **Operators, place of duty.**—(*a*) Except as may be provided in the rules governing a particular class of station, one or more licensed radio operators of the grade specified by these rules and regulations shall be on duty at the place where the transmitting apparatus of each licensed radio sta-

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[1] Wherever the term "license" is used generally to denote an authorization from the Commission, it includes both "license," "permit" and "authorization."

[2] By Order No. 126, dated August 21, 1945, certain railroad employees were authorized to operate radio transmitting apparatus for use in connection with railroad operations without an operator's license upon compliance by the affected employee and the employing railroad with the condition of the Commission's order.

[3] By Commission Order No. 133, dated May 10, 1946, effective June 1, 1946, the Commission waived the requirements for the operation of mobile or portable radio transmitting apparatus by a licensed operator in the Emergency, Miscellaneous, Railroad and Experimental Services (Parts 5, 10, 11 and 16 of the Commission's Rules) subject to certain conditions stated in the Order. Those provisions of Part 13 of the Commission's Rules that are inconsistent with the provisions of Order No. 133 are suspended.

[4] See section 13.61.

[5] By Order No. 136, the Commission cancelled Order No. 97 effective June 30, 1946, provided however, that all Temporary Limited Radiotelegraph Second Class Operator Licenses outstanding at time of cancellation shall remain valid according to the respective terms thereof.

tion is located and in actual charge thereof whenever it is being operated; *Provided, however,* That: (1) Subject to the provisions of paragraph (*b*) of this section, in the case of a station licensed for service other than broadcast, where remote control of the transmitting apparatus has been authorized to be used, the Commission may modify the foregoing requirements upon proper application and showing being made so that such operator or operators may be on duty at the control point in lieu of the place where the transmitting apparatus is located. (2) In the case of two or more stations, except amateur and broadcast, licensed in the name of the same person to use frequencies above 30 megacycles only, a licensed radio operator holding a valid radiotelegraph or radiotelephone first- or second-class license who has the station within his effective control may be on duty at any point within the communication range of such stations in lieu of the transmitter location or control point during the actual operation of the transmitting apparatus and shall supervise the emissions of all such stations so as to insure the proper operation in accordance with the station license.

(*b*) An operator may be on duty at a remote control point in lieu of the location of the transmitting apparatus in accordance with the provisions of paragraph (*a*)(1) of this section, provided, that all of the following conditions are met: (1) The transmitter shall be so installed and protected that it is not accessible to other than duly authorized persons. (2) The emissions of the transmitter shall be continuously monitored at the control point by a licensed operator of the grade specified for the class of station involved. (3) Provision shall be made so that the transmitter can quickly and without delay be placed in an inoperative condition by the operator at the control point in the event there is a deviation from the terms of the station license. (4) The radiation of the transmitter shall be suspended immediately when there is a deviation from the terms of the station license.

APPLICATIONS

§ 13.11 **Procedure.**—(*a*) *General.*—The application in the prescribed form and including all required subsidiary forms and documents, properly completed and signed shall be submitted in person or by mail to the office at which the applicant desires his application to be considered and acted upon, which office will make the final arrangements for conducting any required examination. If the application is for renewal of license, it must be submitted during the last year of the license term, and if all prescribed service requirements are fulfilled,[7] the renewal license may be issued by mail. A renewal application shall also be accompanied by the license to be renewed.

(*b*) *Restricted radiotelephone operator permit.*—No oral or written examination is required for this permit. If the application is properly completed and signed, and if the applicant is found to be qualified, the permit may be issued forthwith by personal delivery to the applicant or by mail.

§ 13.12 **Special provisions, radiotelegraph first class.**—An applicant for the radiotelegraph first-class operator license must be at least 21 years of age at the time the license is issued and shall have had an aggregate of 1 year of satisfactory service as a radiotelegraph operator manipulating the key of a manually operated radiotelegraph station on board a ship or in a manually operated coastal telegraph station.

EXAMINATIONS

§ 13.21 **Examination elements.**—Written examinations will comprise questions from one or more of the following examination elements:

1. *Basic law.*—Provisions of law and regulation with which every operator should be familiar.
2. *Basic theory and practice.*—Technical matters appropriate for every class of license except restricted radiotelephone operator permit.
3. *Radiotelephone.*—Additional matters, both legal and technical, including radiotelephone theory and practice.
4. *Advanced radiotelephone.*—Theory and practice applicable to broadcast station operation.
5. *Radiotelegraph.*—Additional matters, both legal and technical, including radiotelegraph theory and practice.
6. *Advanced radiotelegraph.*—Radiotelegraph theory and practice of wider scope, particularly with respect to ship radio matters (direction finders, ship radiotelephone stations, spark transmitters, etc.).
7. *Aircraft radiotelegraph.*—Basic theory and practice in the operation of radio communication and radio navigational systems in general use on aircraft.

§ 13.22 **Examination requirements.**—Applicants for original licenses will be required to pass examinations as follows:

(*a*) Radiotelephone second-class operator license:

(1) Ability to transmit and receive spoken messages in English.

(2) Written examination elements: 1, 2, and 3.

(*b*) Radiotelephone first-class operator license:

(1) Ability to transmit and receive spoken messages in English.

(2) Written examination elements: 1, 2, 3, and 4.

(*c*) Radiotelegraph second-class operator license:

(1) Ability to transmit and receive spoken messages in English.

(2) Transmitting and receiving code test of sixteen (16) code groups per minute.

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[7] See section 13.28.

(3) Written examination elements: 1, 2, 5, and 6.

(*d*) Radiotelegraph first-class operator license:

(1) Ability to transmit and receive spoken messages in English.

(2) Transmitting and receiving code test of twenty-five (25) words per minute plain language and twenty (20) code groups per minute.

(3) Written examination elements: 1, 2, 5, and 6.

(*e*) Restricted radiotelephone operator permit: No oral or written examination is required for this permit. In lieu thereof, applicants will be required to certify in writing to a declaration which states that the applicant has need for the requested permit; can receive and transmit spoken messages in English; can keep at least a rough written log in English or in some other language in general use that can be readily translated into English; is familiar with the provisions of treaties, laws and rules and regulations governing the authority granted under the requested permit; and understands that it is his responsibility to keep currently familiar with all such provisions.

(*f*) Restricted radiotelegraph operator permit:

(1) Transmitting and receiving code text of sixteen (16) code groups per minute.

(2) Written examination elements: 1, 2, and 5.

§ 13.23 **Form of writing.**—Written examination shall be in English and shall be written by the applicant in longhand in ink, except that diagrams may be in pencil.

§ 13.24 **Passing mark.**—A passing mark of 75 percent of a possible 100 percent will be required on each element of a written examination.

§ 13.25 **New class, additional requirements.**—The holder of a license, who applies for another class of license, will be required to pass only the added examination elements for the new class of license. However, no person holding a new, duplicate, or replacement restricted radiotelephone operator permit issued upon the basis of a declaration, or a renewed restricted radiotelephone operator permit which renews a permit issued upon the basis of a declaration, shall, by reason of the declaration or the issuance of the permit based thereon, be relieved of qualifying by examination on any phase of the subject matter of the declaration when applying for any other operator license or permit for which examination on any subject matter is required.

§ 13.26 **Canceling and issuing new licenses.**—If the holder of a license qualifies for a higher class in the same group, the license held will be canceled upon the issuance of the new license. Similarly, if the holder of a restricted operator permit qualifies for a first- or second-class operator license of the corresponding type, the permit held will be canceled upon issuance of the new license.

§ 13.27 **Eligibility for reexamination.**—An applicant for fails an examination element will be ineligible for 2 months [8] to take an examination for any class of license requiring that element. Examination elements will be graded in the order listed,[9] and an applicant may, without further application, be issued the class of license for which he qualifies.

§ 13.28 **Renewal service requirements, renewal examinations, and exceptions.**—A restricted radiotelephone operator permit or an aircraft radiotelephone operator authorization is not renewable but must always be obtained as a new permit or authorization in each instance. A license of any other class may be renewed without examination provided that the service record on the reverse side of the license shows at least two years of satisfactory service in the aggregate during the license term and while actually employed as a radio operator under that license. If this two year renewal service requirement is not fulfilled, but the service record shows at least one year of satisfactory service in the aggregate during the last three years of the license term and while actually employed as a radio operator under that license, the license may be renewed upon the successful completion of a renewal examination, which may be taken at any time during the final year of the license term or during a one year period of grace after the date of expiration [10] of the license sought to be renewed. The renewal examination will consist of the highest numbered examination element normally required for a new license of the class sought to be renewed, plus the code test (if any) required for such a new license. If the renewal examination is not successfully completed before expiration of the aforementioned one year period of grace, the license will not be renewed on any basis.

CODE TESTS

§ 13.41 **Transmitting speed requirements.**—An applicant is required to transmit correctly in the International Morse code for 1 minute at the rate of speed prescribed in this part for the class of license desired.

§ 13.42 **Transmitting test procedure.**—Transmitting tests shall be performed by the use of the conventional Morse key except that a semi-automatic key, if furnished by the applicant, may be used in transmitting code tests of 25 words per minute.

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[8] A month after date is the same day of the following month, or if there is no such day, the last day of such month. This principle applies for other periods. For example, in the case of the 2-month period to which this note refers, an applicant examined December 1 may be reexamined February 1, and an applicant examined December 29, 30, or 31 may be reexamined the last day of February, while one examined February 28 may be reexamined April 28.

[9] See section 13.21.

[10] With respect to licenses which expired between July 1, 1948, and September 1, 1949, the renewal examination (where required) may be taken during a period of one year commencing on September 1, 1949, and ending with August 31, 1950.

§ 13.43 **Receiving speed requirements.**—An applicant is required to receive the International Morse code by ear, and legibly transcribe, consecutive words or code groups for a period of 1 minute without error at the rate of speed specified in the rules for the class of license for which the application is made.

§ 13.44 **Receiving test procedure.**—Receiving code tests shall be written in longhand either in ink or pencil except that in the case of the 25 words per minute code test a typewriter may be used when furnished by the applicant.

§ 13.45 **Computing word or code groups.**—Each five characters shall be counted as one word or code group. Punctuation marks or figures count as two characters.

SCOPE OF AUTHORITY

§ 13.61 **Operating authority.**—The various classes of commercial radio operator licenses issued by the Commission authorize the holders thereof to operate radio stations, except amateur, as follows:[11]

(*a*) *Radiotelegraph first-class operator license.*—Any station except—

(1) Stations transmitting television, or

(2) Any of the various classes of broadcast stations other than remote pickup and ST broadcast stations, or

(3) On a cargo vessel (other than a vessel operated exclusively on the Great Lakes) required by treaty or statute to be equipped with a radiotelegraph installation, the holder of this class of license may not act as chief or sole operator until he has had at least 6 months' satisfactory service in the aggregate as a qualified radiotelegraph operator in a station on board a ship or ships of the United States.

(4) On an aircraft employing radiotelegraphy, the holder of this class of license may not operate the radiotelegraph station during the course of normal rendition of service unless he has satisfactorily completed a supplementary examination qualifying him for that duty, or unless he has served satisfactorily as chief or sole radio operator on an aircraft employing radiotelegraph prior to February 15, 1950. The supplementary examination shall consist of:

(i) Written examination element: 7

(*b*) *Radiotelegraph second-class operator license.*—Any station except—

(1) Stations transmitting television, or

(2) Any of the various classes of broadcast stations other than remote pickup and ST broadcast stations, or

(3) On a passenger[12] vessel required by treaty or statute to maintain a continuous radio watch by operators or on a vessel having continuous hours of service for public correspondence, the holder of this class of license may not act as chief operator, or

(4) On a vessel (other than a vessel operated exclusively on the Great Lakes) required by treaty or statute to be equipped with a radiotelegraph installation, the holder of this class of license may not act as chief or sole operator until he has had at least 6 months' satisfactory service in the aggregate as a qualified radiotelegraph operator in a station on board a ship or ships of the United States.

(5) On an aircraft employing radiotelegraph, the holder of this class of license may not operate the radiotelegraph station during the course of normal rendition of service unless he is at least eighteen (18) years of age and has satisfactorily completed a supplementary examination qualifying him for that duty, or unless he has served satisfactorily as chief or sole radio operator on an aircraft employing radiotelegraphy prior to February 15, 1950. The supplementary examination shall consist of:

(i) Transmitting and receiving code test at twenty-five (25) words per minute plain language and twenty (20) code groups per minute.

(ii) Written examination element: 7

(*c*) *Restricted radiotelegraph operator permit.*—Any station except—

(1) Stations transmitting television, or

(2) Any of the various classes of broadcast stations other than remote pickup and ST broadcast stations, or

(3) Ship stations licensed to use telephony for communication with coastal telephone stations, or

(4) Radiotelegraph stations on board a vessel required by treaty or statute to be equipped with a radio installation, or

(5) Ship telegraph, coastal telegraph or marine-relay stations open to public correspondence, or

(6) Aircraft radio stations while employing radiotelegraphy;

Provided, That in the case of equipment designed for and using telephone or facsimile transmissions: (1) Such operator is prohibited from making adjustments that may result in improper transmitter operation, and (2) the equipment is so designed that none of the operations necessary to be performed during the course of normal rendition of service may cause off-frequency operation or result in any unauthorized radiation, and (3) any needed adjustments of the transmitter which may affect proper operation of the station are regularly made by or in the presence of an operator holding a first- or second-class license, either radiotelephone or radiotelegraph, who shall be responsible for the proper operation of the equipment.

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[11] For temporary authority granted holders of valid first and second class operator licenses, either radiotelephone or radiotelegraph, to perform adjustments, servicing and maintenance of ship radar stations licensed in the Ship Service, see footnote 71, § 8.195, of the Commission's rules governing ship service.

[12] A ship shall be considered a passenger ship if it carries or is licensed or certificated to carry more than 12 passengers. A cargo ship means any ship not a passenger ship.

(*d*) *Radiotelephone first-class operator license.*—Any station except—

(1) Stations transmitting telegraphy by any type of the Morse Code, or

(2) Ship stations licensed to use telephony and power in excess of 100 watts for communication with coastal telephone stations.

(*e*) *Radiotelephone second-class operator license.*—Any station except—

(1) Stations transmitting telegraphy by any type of the Morse Code, or

(2) Standard broadcast stations, or

(3) International broadcast stations, or

(4) FM broadcast stations, or

(5) Non-commercial educational FM broadcast stations with transmitter power rating in excess of 1 kilowatt, or

(6) Television broadcast stations licensed for commercial operation, or

(7) Ship stations licensed to use telephony and power in excess of 100 watts for communication with coastal telephone stations.

(*f*) *Restricted radiotelephone operator permit.*—Any station except—

(1) Stations transmitting television, or

(2) Stations transmitting telegraphy by any type of the Morse Code, or

(3) Any of the various classes of broadcast stations other than remote pickup and ST broadcast stations, or

(4) Coastal telephone stations or coastal harbor stations other than in the Territory of Alaska, or

(5) Ship stations licensed to use telephony for communication with coastal telephone stations;

Provided, That, (1) Such operator is prohibited from making any adjustments that may result in improper transmitter operation, and (2) the equipment is so designed that none of the operations necessary to be performed during the course of normal rendition of service may cause off-frequency operation or result in any unauthorized radiation, and (3) any needed adjustments of the transmitter that may affect the proper operation of the station are regularly made by or in the presence of an operator holding a first- or second-class license, either radiotelephone or radiotelegraph, who shall be responsible for the proper operation of the equipment.

§ 13.62 **Special privileges.**—In addition to the operating authority granted under § 13.61, the following special privileges are granted the holders of commercial radio operator licenses:

(*a*) The holder of any class of commercial radio operator license may operate any station in the experimental service while using frequencies solely above 300 megacycles.

(*b*) The holder of any class of radiotelephone operator license, whose license authorizes him to operate a station while transmitting telephony, may operate the same station when transmitting on the same frequencies, any type of telegraphy under the following conditions:

(1) When transmitting telegraphy by automatic means for identification, for testing, or for actuating an automatic selective signaling device, or

(2) When properly serving as a relay station and for that purpose retransmitting by automatic means, solely on frequencies above 50 megacycles, the signals of a radiotelegraph station, or

(3) When transmitting telegraphy as an incidental part of a program intended to be received by the general public, either directly or through the intermediary of a relay station or stations.

§ 13.63 **Operator's responsibility.**—The licensed operator responsible for the maintenance of a transmitter may permit other persons to adjust a transmitter in his presence for the purpose of carrying out tests or making adjustments requiring specialized knowledge or skill, provided that he shall not be relieved thereby from responsibility for the proper operation of the equipment.

§ 13.64 **Obedience to lawful orders.**—All licensed radio operators shall obey and carry out the lawful orders of the master or person lawfully in charge of the ship or aircraft on which they are employed.

§ 13.65 **Damage to apparatus.**—No licensed radio operator shall willfully damage, or cause or permit to be damaged, any radio apparatus or installation in any licensed radio station.

§ 13.66 **Unnecessary, unidentified, or superfluous communications.**—No licensed radio operator shall transmit unnecessary, unidentified, or superfluous radio communications or signals.

§ 13.67 **Obscenity, indecency, profanity.**—No licensed radio operator or other person shall transmit communications containing obscene, indecent, or profane words, language, or meaning.

§ 13.68 **False signals.**—No licensed radio operator shall transmit false or deceptive signals or comunications by radio, or any call letter or signal which has not been assigned by proper authority to the radio station he is operating.

§ 13.69 **Interference.**—No licensed radio operator shall willfully or maliciously interfere with or cause interference to any radio communication or signal.

§ 13.70 **Fraudulent licenses.**—No licensed radio operator or other person shall obtain or attempt to obtain, or assist another to obtain, an operator's license by fraudulent means.

MISCELLANEOUS

§ 13.71 **Issue of duplicate or replacement licenses.**—(*a*) An operator whose license, permit or authorization has been lost, mutilated or destroyed shall immediately notify the Commission. A properly executed application for duplicate should be submitted to the office of issue, embodying a statement of the circumstances involved in the loss, mutilation or destruction of the license or permit for which a duplicate is desired. If the license or permit has been lost, the applicant must state that reasonable search has been made for it, and further, that in the event it be found either the original or the duplicate will be returned for cancellation. The applicant should also submit documentary evidence of the service that has been obtained under the original license or permit, or a statement under oath or affirmation embodying that information.

(*b*) The holder of any license, permit or authorization whose name is legally changed may make application for replacement document to indicate the new legal name, by submitting a properly executed application to the office of issue, accompanied by the license, permit or authorization affected and by documentary evidence of the legality of the name change.

§ 13.72 **Exhibiting signed copy of application.**—When a duplicate or replacement operator license or permit has been requested, or request has been made for renewal upon service or for an endorsement or a verification card, the operator shall exhibit in lieu of the original document a signed copy of the application which has been submitted by him.

§ 13.73 **Verification card.**—The holder of an operator license or permit of the diploma form (as distinguished from such document of the card form) may, by filing a properly executed application accompanied by his license or permit, obtain a verification card.[13] This card may be carried on the person of the operator in lieu of the original license or permit when operating any station at which posting of an operator license is not required: *Provided,* That the license is readily accessible within a reasonable time for inspection upon demand by an authorized Government representative.

§ 13.74 **Posting requirements for operator.**—(*a*) Performing duties other than, or in addition to, service or maintenance, at two or more stations. The holder of any class of radio operator license or permit of the diploma form (as distinguished from the card form) who performs any radio operating duties, as contrasted with but not necessarily exclusive of service or maintenance duties, at two or more stations at which posting of his license or permit is required shall post at one such station his operator license or permit and shall post at all other such stations a duly issued verified statement.[14]

(*b*) Performing service or maintenance duties at one or more stations. The holder of a radiotelephone or radiotelegraph first- or second-class radio operator license who performs, or supervises, and is responsible for service or maintenance work on any transmitter of any station for which a station license is required, shall post his license at the transmitter involved whenever the transmitter is in actual operation while service or maintenance work is being performed: *Provided,* That in lieu of posting his license, he may have on his person either his license or a verification card.[13] *And provided further,* That if he performs operating duties in addition to service or maintenance duties he shall, in lieu of complying with the foregoing provisions of this paragraph, comply with the posting requirements applicable to persons performing such operating duties, as set forth in paragraph (*a*) of this section, and in the rules and regulations applicable to each service.

§ 13.75 **Record of service and maintenance duties performed.**—In every case where a station log or service and maintenance records are required to be kept and where service or maintenance duties are performed which may affect the proper operation of a station, the responsible operator shall sign and date an entry in the log of the station concerned, or in the station maintenance records if no log is required, giving:

(*a*) Pertinent details of all service and maintenance work performed by him or under his supervision;

(*b*) His name and address; and

(*c*) The class, serial number and expiration date of his license;

Provided, That the responsible operator shall not be subject to requirements (*b*) and (*c*) of this section in relation to a station, or stations of one license at a single location, at which he is regularly employed as an operator on a full time basis and at which his license is properly posted.

SERVICE

§ 13.91 **Endorsement of service record.**—A station licensee, or his duly authorized agent, or the master of a vessel acting as the agent of a licensee, shall endorse the service record appearing on said operator license, showing the call letters and types of emission of the station operated, the nature and period of employment, and quality of performance of duty.

§ 13.92 **Aviation service endorsement.**—If the operator has operated more than three stations in the aviation service, the service may be shown by giving the name of the aviation chain or company in lieu of listing the call letters of the several stations.

§ 13.93 **Service acceptability.**—Credit will be allowed only for satisfactory service obtained under conditions that required the employment of licensed operators, or when obtained at United States Government stations.

§ 13.94 **Statement in lieu of service endorsement.**—The holder of a radiotelegraph license or a restricted radiotelegraph operator permit desiring an endorsement to be placed thereon attesting to an aggregate of at least 6 months' satisfactory service as a qualified operator on a vessel of the United States, may, in the event documentary evidence cannot be produced, submit to any office of the Commission a statement under oath accompanied by the license to be endorsed, embodying the following:

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[13] Form 758-F.

[14] Form 759.

(*a*) Names of ships at which employed;
(*b*) Call letters of stations;
(*c*) Types of emission used;
(*d*) Type of service performed as follows:
  (1) Manual radiotelegraph operation only; and
  (2) Transmitter control only; or
  (3) Combination of (1) and (2) running concurrently;

(*e*) Whether service was satisfactory or unsatisfactory;
(*f*) Period of employment;
(*g*) Name of master, employer, licensee, or his duly authorized agent.

Commercial Radio Operators Examination Procedure—The examination for radio operators license of various classes, as defined in Rules governing commercial operators as explained in Chapter 20, is divided into seven elements. Each element, except Element one (1), comprises 10 or 20 pages of five questions each, totaling 50 or 100 questions. No credit is allowed if a question is unanswered, or if more than one solution is given by the applicant, or if a solution is only partially correct.

In all computations a slide rule may be used, and normal slide-rule accuracy in the solutions will be accepted. The scope of the examinations is not such as to require a slide rule but one may use it in solving a problem to gain time and obviate the use of side paper. All paper for writing examinations is furnished. Books or other reference material are not permitted to be held in the possession of the applicant while writing the examination. All work performed or side paper must be turned in with the other material associated with the examination.

The examination questions in Element 1 are devoted to the Communications Act of 1934, The International Radio Regulations (Cairo Revision, as shown in Chapter 20) and the Rules and Regulations of the Federal Communications Commission (Chapter 20).

The questions comprising the Elements 2 to 7, inclusive, are of the multiple choice and hence do not require or permit an essay or explanatory type of answer. The applicant must select the one and only one answer that he considers the correct answer to the question. The applicant may find questions in the examination that require a simple mathematical problem, hence the use of slide rule may be helpful. Also, the applicant may be required to draw a simple diagram of some fundamental radio circuit, complete a diagram, or make corrections to an incorrect hook-up. In making corrections, any connection which is eliminated must be crossed out by means of a wavy line or by short diagonal cross-lines.

The following is a sample of a multiple choice question similar to those employed in the commercial operators examination:

A Hexode tube has:

1. A cold cathode
2. Five elements
3. Six elements
4. Six grids
5. Two plates.

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Applicants preparing for the commercial operators examination should obtain a copy of the booklet entitled, "Study Guide and Reference Material for Commercial Radio Operator Examination," which can be procured from the Superintendent of Documents, Washington, D. C., at a cost of twenty-five cents.

Examinations are conducted by field representatives of the Commission at their headquarters and many examining points throughout the nation on schedule. Arrangements for examination may be completed by corresponding with the nearest field office to the applicant or by writing the Secretary, Federal Communications Commission, Washington, D. C.

RULES GOVERNING SHIP SERVICE

DEFINITIONS

The following definitions shall apply to the provisions of this part:

AUTHORITY

§ 8.1 **Communications Act.**—The term "Communications Act" means the Communications Act of 1934, as amended.

§ 8.2 **Ship Act.**—The term "Ship Act" means the act approved June 24, 1910, as amended, requiring apparatus and operators for radio communication on certain Great Lakes steamers.

§ 8.3 **Conventions.**—(*a*) The term "Safety Convention" means the International Convention for the Safety of Life at Sea in force[15] and the regulations referred to therein.

(*b*) The term "International General Radio Regulations" means the General Radio Regulations of Cairo, 1938, annexed to the International Telecommunications Convention of Madrid, 1932.

§ 8.4 **Commission.**—The term "Commission" means the Federal Communications Commission.

§ 8.5 **Standards of Good Engineering Practice for Ship Stations.**—The term "Standards of Good Engineering Practice for Ship Stations" as used in this part means a supplemental publication bearing this title as approved and promulgated by the Commission.

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[15] The International Convention for the Safety of Life at Sea, London, 1929, became effective for the United States on November 7, 1936.

CERTIFICATES

§ 8.6 **Exemption certificate.**—The term "Exemption Certificate" means a certificate issued to a ship which is granted exemption from applicable provisions of the Safety Convention.[15]

§ 8.7 **Safety certificate.**—The term "Safety Certificate" means a certificate issued upon application, after inspection and survey by proper authorities, to a passenger ship which complies in an efficient manner with the requirements of the Safety Convention.[15]

§ 8.8 **Safety radiotelegraphy certificate.**—The term "Safety Radiotelegraphy Certificate" means a certificate issued upon application, after inspection by proper authorities, to any ship, other than a passenger ship, which complies in an efficient manner with the requirements of the Safety Convention.[15]

INSTALLATIONS

§ 8.9 **Main installation.**—The term "main installation" means a radio installation on board a vessel, including a main transmitter and a main receiver, capable of being used for transmitting and receiving signals to and from other stations in the maritime mobile service; independent of the emergency or reserve installation on a passenger or cargo ship; or under specified conditions [16] independent of the emergency power supply on a cargo ship.

§ 8.10 **Emergency or reserve installation.**—The term "emergency or reserve installation" or "emergency installation" means a radio installation on board a vessel, including an emergency transmitter, an emergency receiver, emergency electric lights and an emergency power supply, capable of being used for transmitting and receiving signals to and from other stations in the maritime mobile service when energized solely by the emergency power supply.

§ 8.11 **Emergency power supply.**—The term "emergency power supply" means an immediately available source or sources of power on board a ship, independent of the propelling power of the ship and any other electrical system, capable of simultaneously energizing all components of the emergency or reserve installation.

§ 8.12 **Direction finder.**—The term "direction finder" means a radio receiving device which permits determination of the line of travel of radio waves at the point of reception.

§ 8.13 **Energize.**—The term "energize," as applied in these regulations, to transmitters, receivers, and other component equipment of ship radio installations, means to supply with power as necessary to provide normal and effective operation of this equipment.

TRANSMITTERS

§ 8.14 **Emergency transmitter.**—The term "emergency transmitter" means a transmitter immediately available in a ship station for emergency communication and capable of being energized solely by the emergency power supply.

§ 8.15 **Main transmitter.**—The term "main transmitter" means a radio transmitter regularly available in a ship station for routine communication which ordinarily is energized by a source of power other than the emergency power supply.

RECEIVERS

§ 8.16 **Automatic alarm receiver.**—The term "automatic alarm receiver" means a complete receiving, selecting, and warning device capable of being actuated automatically by intercepted radio-frequency waves forming the international automatic alarm signal, as this signal is specified by the International General Radio Regulations.

§ 8.17 **Direction finder receiver.**—The term "direction finder receiver" means a receiver which is a component of a radio direction finder.

§ 8.18 **Emergency receiver.**—The term "emergency receiver" means a receiver immediately available in a ship station for emergency communication and capable of being energized solely by the emergency power supply.

§ 8.19 **Main receiver.**—The term "main receiver" means a receiver regularly available in a ship station for routine communication which ordimarily is energized by a source of power other than the emergency power supply.

SERVICE OF A SHIP STATION

§ 8.20 **Maritime mobile service.**[17]—The general term "maritime mobile service" means a radio service carried on between maritime mobile stations and land stations, and by maritime mobile stations communicating among themselves.

§ 8.21 **Ship service.**[17]—The term "ship service" means a radio communication service of *public correspondence* carried on between ship stations and coastal stations or between ship stations and maritime mobile stations.

§ 8.22 **Antenna resistance.**—"Antenna resistance" means the total resistance of the transmitting antenna system at the operating frequency and at the point at which the antenna current is measured.

§ 8.23 **Final radio stage.**—"Final radio stage" means the oscillator or radio-frequency-power amplifier stage which supplies power to the antenna.

§ 8.24 **Emergency communication.**—The term "emergency communication" with respect to ship stations means the transmission or reception of distress, alarm, urgent, or safety signals, or messages relating thereto, or any matter relating to the safety of life or property, or occasional operation of equipment for determining whether or not the radio installation is in good working condition.

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[16] See sec. 354 (a) of the Communications Act.

[17] The term does not apply to the use of radar installations on board ship except where radar is specifically mentioned.

§ 8.25 **Routine communication.**—The term "routine communication" with respect to ship stations means all operation authorized for such stations which is not included in the definition of "emergency communication."

§ 8.26 **Hours of service.**—The term "hours of service" or "duration of service" means the time during which a ship station is held open for the exchange of message traffic with other stations in the maritime mobile service.

STATIONS

§ 8.27 **Ship station.**—The term "ship station" means a radio station licensed for ship service which is located on board a ship actually afloat and not permanently moored.

§ 8.28 **Ship telegraph station.**—The term "ship telegraph station" means a ship station licensed to use, and capable of using, type A–1, A–2, or B [18] emission.

§ 8.29 **Ship telephone station.**—The term "ship telephone station" means a ship station licensed to use, and capable of using, type A–3 emission for speech transmission.

§ 8.30 **Maritime mobile station.**—The general term "maritime mobile station" means a ship station, or an aircraft station at sea.

MISCELLANEOUS

§ 8.31 **Radio watch.**—The term "radio watch" or "watch" means the service performed by a qualified operator when on duty in the radio room of a vessel listening for signals of other stations on the international calling and distress frequency, 500 kilocycles, and at all other times when such operator, in conformity with the International General Radio Regulations and subject to authority of the master, is engaged in transmitting or receiving signals or messages on any authorized frequency, to or from any station in the maritime mobile service, or in receiving from any station time signals, weather reports, hydrographic reports, reports regarding aids to navigation, authorized press material, or information regarding the safety of life or property at sea.

§ 8.32 **Day operation.**—For the purpose of this part, where the word "day" occurs in reference to a specific frequency or to a specific operating power, such use of the word shall be construed to mean that period of time included between two hours after local sunrise and two hours before local sunset.

§ 8.33 **Automatic-alarm-signal keying device.**—The term "automatic-alarm-signal keying device" means a device capable of automatically keying the radiotelegraph transmitter(s) on board a ship so as to transmit the international automatic-alarm signal, as this signal is specified by the International General Radio Regulations.

SCOPE OF SHIP SERVICE

§ 8.35 **Scope of ship service.**—(*a*) In addition to signals, communications and messages relating to the safety of life and property at sea and the safety of navigation, a ship station shall, within the scope of its normal operations, without discrimination and *upon reasonable demand,* transmit any messages which originate with passengers or members of the crew on board that relate solely to the personal or business affairs of those on board or to the business of the particular ship as a medium of transportation or as a carrier of passengers or goods. Other communications, except as provided in subsection (*c*) of this section, may be transmitted only in accordance with special authority granted by the Commission.

(*b*) A ship station shall, within the scope of its normal operations and without discrimination, acknowledge all calls directed to it and receive from maritime mobile stations and from public coastal stations all messages and communications which are addressed to the ship or to any person(s) on board and which are for termination on such ship.

(*c*) At the request of any other station in the maritime mobile service, a ship station may, within the scope of its normal operations, accept messages or communications from such station for retransmission to any other station in the maritime mobile service. Whenever such messages or communications have been received and acknowledged by a ship station for this purpose, it shall be incumbent upon that station to retransmit the message as directed with the least possible delay.

(*d*) No charge shall be made for ship service except by ship stations having tariffs duly filed with the Commission setting forth the charges for such service.

(*e*) Except as it may be regulated by law or international agreement or by rules of this Commission, the radio service of a ship station shall be under the supreme control of the master, as provided in section 358 of the act.

(*f*) Each ship station shall be responsible for the payment of all charges accruing to any other station or facilities for the handling or forwarding of messages or communications transmitted by the ship station concerned.

§ 8.36 **Percentage modulation (amplitude).**—"Percentage modulation" with respect to an amplitude modulated wave means the ratio of half the difference between the maximum and minimum amplitudes of the amplitude modulated wave to the average amplitude, expressed in percentage.[19]

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[18] Type B emission is not authorized for ship stations of United States registry, except in case of distress. See sec. 8.80.

[19] In linear modulation the average amplitude of the envelope is equal to the amplitude of the unmodulated wave, provided there is no zero-frequency component in the modu-

§ 8.37 **Station licensee.**—"Station licensee"[20] means the holder of a radio station license.

§ 8.38 **Operator, place of duty.**—One or more licensed operators of the grade specified by these rules and regulations shall be on duty at the place where the transmitting apparatus of each station is located and in actual charge thereof whenever it is being operated.

§ 8.39 **Maximum rated carrier power.**—"Maximum rated carrier power" is the maximum power at which the transmitter can be operated satisfactorily and is determined by the design of the transmitter and the type and number of vacuum tubes used in the final radio stage.

§ 8.40 **Plate input power.**—"Plate input power" means the product of the direct plate voltage applied to the tubes in the final radio stage and the total direct current flowing to the plates of these tubes, measured without modulation.

OPERATING PROCEDURE

§ 8.41 **Interference to be minimized.**—(*a*) Before transmitting a ship station shall make sure that it will not produce harmful interference with communications being carried on within its range. If such interference is likely, the station shall wait until the existing communications, which it may disturb, have been concluded; with due regard, nevertheless, for the priority of communications designated by section 8.42. The transmission of unnecessary or superfluous communications is forbidden.

(*b*) Whenever a radiocommunication is already in progress between two ship stations or between a ship and a coastal station and it appears to be interfered with by a subsequent transmission from another ship station, the latter must cease transmitting at the first request of either of the other two, except as priority may be otherwise determined by section 8.42. The station requesting this cessation must indicate the approximate length of the wait imposed upon the ship station whose transmission is suspended.

§ 8.42 **Order of priority of communications.**—The order of priority of radiotelegraph and radiotelephone communications in the maritime mobile service on any frequency used for this service shall be as follows:[21]

(*a*) Distress calls, distress messages, and distress traffic.

(*b*) Communications preceded by an urgent signal.

(*c*) Communications preceded by a safety signal.

(*d*) Communications relative to radio direction-finder bearings.

(*e*) Government radiotelegrams for which priority right has not been waived.

(*f*) All other communications.

§ 8.43 **Mobile station in distress.**—No provision of these rules or of any regulations shall prevent a mobile station in distress from using any means available to it for drawing attention, signalling its position, and obtaining help.

§ 8.44 **Transmission of alarm signal.**—When a distress call has been transmitted and was not preceded by the international automatic alarm signal, a station in the maritime mobile service within the general vicinity of the station which transmitted the distress call, may transmit the alarm signal (using type A-2 or B emission) on the frequency 500 kilocycles upon authorization of the master or other person responsible for the station, provided every reasonable precaution is observed not to interfere with the acknowledgment of receipt of the distress call nor with distress traffic already in progress.

§ 8.45 **Repetition of distress call.**—If a ship station has heard a distress call or distress message for which acknowledgment of receipt has not been given promptly, and the ship station itself is not in a position to render assistance, the ship station, subject to authority of the master, shall make every effort possible to attract the attention of any station in the maritime mobile service which appears to be in a position to render assistance, and for this purpose transmission of the distress call and distress message may be repeated on 500 and 8280 kilocycles and on such other frequencies as may be deemed necessary. The ship station, if authorized by the master, may transmit, for this purpose, the international automatic alarm signal on the frequency 500 kilocycles (using type A-2 or B emission) prior to repetition of the distress call and message. In the event the alarm signal is transmitted, a sufficient period of time to allow operators warned by the alarm signal to go on watch shall be observed after transmission of the alarm signal and before retransmission of the distress message.

§ 8.46 **Repetition of alarm signal.**—A ship station intercepting an international automatic alarm signal which appears to be not duly effective by reason of improper timing, improper type of emission, insufficient signal strength, interference, or excessive deviation from 500 kilocycles, if authorized by the master, may repeat the transmission of this signal on the frequency 500 kilocycles (using type A-2 or B emission) to be followed by a repetition of the distress call and distress message provided all reasonable precaution is taken by such station not to interfere with acknowledgment of receipt of the

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lating signal wave (as in telephony). For modulating signal waves having unequal positive and negative peaks, positive and negative modulation factors may be defined as the ratios of the maximum departures (positive and negative) of the envelope from its average value, to its average value.

[20] A station licensee may hold more than one license. The provisions of any rules of the Commission imposing requirements on licensees shall be considered to apply only with respect to the particular class of station to which the rule relates unless the context otherwise clearly requires.

[21] "Distress," "urgent," and "safety" signals are described in art. 24 of the International General Radio Regulations.

distress call nor with distress traffic already in progress.

§ 8.47 **Limitations relative to A–2 emission.**—(*a*) Beginning January 1, 1941, the use of A–2 emission, which is generated by abrupt[22] interruptions or reductions of the carrier wave, at an audible frequency or frequencies, without reference to the usual interruptions caused by ordinary telegraphic keying, shall be prohibited for ship stations on frequencies below 30,000 kilocycles except when necessary for emergency communication.

(*b*) The use of A–2 emission, which is generated by keying the audible frequency or frequencies used to modulate the carrier wave, without interruption of this carrier wave, is prohibited for ship telegraph stations on radio frequencies below 30,000 kilocycles except when necessary for emergency communication.

§ 8.48 **Priority of operation of ship station.**—From the standpoint of interference, the operation of a ship radio station, including receiving equipment, auto-alarm, and direction finder, installed on board a vessel for safety purposes in compliance with law, shall have priority over the operation of any other radio apparatus on board the same vessel.

§ 8.49 **Special provisions for apparatus employing alternating plate supply (self-rectifying plate supply).**—In the application of these rules to equipment authorized and designed for the use of alternating current or voltage, as plate supply for the final radio stage, the terms "direct current" and "direct voltage" shall be considered as referring to the equivalent effective alternating current and voltage, and terms having possible application only to equipment designed for the use of direct current shall not apply whenever these terms are used in these rules.

§ 8.50 **Communication with coastal-harbor stations.**—All ship telephone stations when operating on a frequency below 3500 kilocycles or above 30,000 kilocycles for communication with a coastal-harbor station in the United States which is open to public correspondence, shall communicate with the nearest station of this class whenever practicable under the prevailing conditions of transmission and reception.

§ 8.51 **Identification of ship station.**—(*a*) The complete name of the vessel on which the ship station is located shall be announced at the beginning and upon completion of any radiotelephone communication carried on by such station.

(*b*) The name, the call lettters, and the class of station (portable-mobile), of a portable-mobile station authorized to be operated on board ships shall be transmitted at the beginning and upon completion of any communication carried on by such station.

§ 8.52 **Monitoring before transmitting.**—Before any signals or communications are transmitted on any frequency, the licensed operator attending the ship station shall first listen on the associated receiving frequency to determine whether transmission by the station will interfere with communication already in progress.

§ 8.53 **Control by coastal station.**—A ship station, when communicating with a coastal station, shall comply with instructions given by that station in all questions relating to the order and time of transmission, to the choice of authorized frequency and to the suspension of communication. This provision does not apply in the event of emergency or distress.

§ 8.54 **Operating procedure for ship radiotelephone stations in the Great Lakes area[23] only.**—(*a*) Except in the event of emergency or distress a ship telephone station shall call the particular station with which it is intended to communicate.

(*b*) Each ship telephone station licensed to transmit on one or more frequencies within the bands 2000–2200 kilocycles and 2734–2742 kilocycles shall maintain, during its hours of service, an efficient watch for the reception of A–3 emission (telephony) on the frequency 2182 kilocycles whenever it is not engaged in communication on other frequencies.

(*c*) The frequency 2182 kilocycles shall be used by ship telephone stations in the Great Lakes area only for:

(1) Initially calling. (Calling any one station shall not exceed one minute in duration.)

(2) Acknowledging calls received on this frequency.

(3) Exchanging operating signals with ship and coastal stations to establish communication on another frequency within the band 2000 to 3000 kilocycles.

(4) Exchanging "distress"[24] and "safety"[25] communications.

If the called station has not answered at the end of the 1-minute period, that station shall not again be called until at least 15 minutes have elapsed. Any one exchange of communications on this frequency, including calls, answers, operating signals, and conversation pertaining to safety shall not exceed 5 minutes in duration. In the event of distress, these time limitations are waived.

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[22] This section relates in particular to the electromechanical transmitting device commonly known as a "chopper," employed mainly in connection with arc transmitters and electron-tube transmitters of early design.

[23] As used herein, the term "Great Lakes area" includes the St. Lawrence River west of Montreal, Province of Quebec.

[24] For this purpose, "distress" communications are construed to be any communications relative to immediate assistance needed by a ship in distress; i.e., a vessel is threatened by serious and imminent danger and immediate assistance is necessary.

[25] For this purpose, "safety" communications are construed to mean communications concerning the safety of a ship as distinguished from distress, or concerning the safety of a person or persons on board or sighted from on board, and communications concerning the safety of navigation or important meteorological warnings.

(*d*) Before transmitting on the frequency 2003 kilocycles or 2738 kilocycles, ship stations shall first establish communication with each other on the frequency 2182 kilocycles by initially calling and answering on the latter frequency.

(*e*) [26] Whenever a ship station intends to communicate with a coastal harbor station by transmitting on any working frequency within the band 2100–2200 kilocycles, the ship station shall initially call or answer the coastal harbor station on the frequency 2182 kilocycles. Except as hereinafter provided, the ship station may transmit on 2118 or 2158 kilocycles only when directed to do so by the coastal harbor station. Without regard to the foregoing limitation, a ship station may initially call [27] on the frequency 2158 kilocycles a coastal harbor station in the United States which has been authorized [28] by the Commission to answer calls from ship stations transmitted initially on 2158 kilocycles. Calling any one station on 2158 kilocycles shall not exceed one minute in duration. If the called station has not answered at the end of the one minute period, that station shall not again be called until at least 15 minutes have elapsed. The foregoing requirements shall in no way limit or delay the handling of distress or emergency communications.

(*f*) Unless otherwise directed by a coastal-harbor station, any one exchange of communications by a ship station transmitting on the frequency 2118, 2158, 4422.5, 6660 or 8820 kilocycles shall not exceed 15 minutes in duration. Subsequent to any one exchange of communications, the same frequency shall not again be used by that ship station until 15 minutes have elapsed, provided that this limitation shall not apply to distress or emergency communication

§ 8.55 **Operating procedure for ship radiotelephone stations on the Mississippi River and connecting inland waters.**—(*a*) Except in the event of emergency or distress, a ship telephone station shall call the particular station with which it intends to communicate. Calling any one station on the frequency 2738, 2782, 4162.5, 6455, 8840, or 11,090 kilocycles shall not exceed 3 minutes in duration. If the called station has not answered at the end of the 3-minute period, that station shall not again be called until at least 15 minutes have elapsed.

(*b*) Unless otherwise directed by a coastal-harbor station, any one exchange of communications by a ship station transmitting on the frequency 2782, 4162.5, 6455, 8840, or 11,090 kilocycles shall not exceed 15 minutes in duration.[29] Subsequent to any one exchange of communications, the same frequency shall not again be used by that ship station until 15 minutes have elapsed, provided that this limitation shall not apply to distress or emergency communication.

(*c*) When communicating on the frequency 2782, 4162.5, 6455, 8840, or 11,090 kilocycles, the transmitter carrier wave of a ship telephone station shall be either automatically "voice controlled" or controlled manually by the person whose speech is being transmitted, in order to avoid the transmission of an unmodulated carrier wave and to facilitate the operation of a simplex circuit.[30]

§ 8.56 **Maintenance tests of licensed stations.**—Station licensees are authorized to carry on such routine tests as may be required for the proper maintenance of the stations under the rules governing the class of station concerned, provided that the tests shall be so conducted as not to cause interference with the service of other stations.

§ 8.57 **National defense; naval instructions regarding ship radio service.**—No provision of the Commission's rules and regulations shall, in time of war, prevent the master of any vessel of the United States from taking any action whatsoever in regard to the radio installation, the operators, the transmission and receipt of messages, and the radio service of the ship whenever in his discretion such action is necessary to carry out the instructions of United States naval control officers and other instructions issued by the Department of the Navy.

§ 8.61 **License period.**—For all ship stations in the Ship Service, the license period shall be as follows:

(*a*) Each station license will be issued for a term of from one to five years from the effective date of grant, the term varying as may be necessary to permit the orderly scheduling of renewal applications.

(*b*) Each station license normally will be renewed, upon proper application, for a term of four years from the effective date of renewal.

§ 8.62 **Classes of ship stations.**—Ship stations will be licensed by classes according to their hours of service, as follows:

(*a*) *First class.*—These stations shall carry on a continuous service whenever the vessel is being navigated or is outside a harbor or port.

(*b*) *Second class.*—These stations shall carry on a designated service of limited duration whenever the vessel is being navigated or is outside a harbor or port; at least during the period designated for ship stations of the second category in the appendix of the International General Radio Regulations, or as otherwise designated by the station license.

(*c*) *Third class.*—These stations, when operated, shall carry on a service the duration of which is undetermined or which is determined by the master of the vessel.

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[26] See also section 7.38 (*c*).

[27] See section 8.52.

[28] The Commission will notify ship station licensees of authorizations which are issued to coastal harbor stations for this purpose.

[29] See also sec. 8.94.

[30] See also sec. 8.93.

§ 8.63 **Posting of licenses.**—The original ship radio station license, and the original license of each operator of the ship station while he is employed or designated as radio operator on the vessel, shall be posted in a conspicuous place in the associated radio operating room on board the ship, except when any operator license has been submitted to the Commission in accordance with relevant provisions of part 13: *Provided,* That the foregoing requirement shall not apply to portable-mobile stations operated on board small boats where posting of licenses is impracticable, upon the express condition that the original portable-mobile station license or a photocopy thereof shall be retained at all times on board the mobile vessel on which the station is currently located, and that the radio operator license of the person operating the station shall be kept in his personal possession on board such vessel whenever the station is being operated: *Provided further,* however, that any operator who holds a restricted radiotelephone operator permit of the card form (as distinguished from the diploma form), and who is employed or designated as radio operator of a ship station, shall not post that permit, but whenever on duty shall keep it in his personal possession.

§ 8.64 **Lifeboat stations.**—Properly licensed [31] lifeboat radio transmitting equipment may be operated for maintenance tests and emergency communication under authority of the regular license of the ship station without a separate license posted in the lifeboat. The call signals to be used by a lifeboat operating under this section shall be the regularly assigned call of the ship station to which the lifeboat is regularly attached, to be followed by the international break sign, BT, and the number of the lifeboat.

§ 8.66 **Authority to communicate with amateur stations.**—Upon formal application being made and duly executed, including a supplemental statement in reference to conditions (*a*) and (*b*) hereinafter specified, the Commission may grant a license, modification of license, renewal of license or special temporary authority, permitting a ship telegraph station, on board a noncommercial vessel or on board a vessel to be used for scientific research or expedition, to transmit on ship telegraph frequencies above 4000 kilocycles designated in the license of such ship station, for the secondary purpose of exchanging radiotelegraph communications directly with licensed amateur stations, on condition that transmission for this purpose shall not interfere with the primary use of these frequencies for normal ship service, and provided the applicant makes a satisfactory showing that:

(*a*) The messages to be exchanged with amateur stations will contain no material relating directly or indirectly to a commercial transaction.

(*b*) Unusual circumstances will be encountered during the contemplated voyage(s) which will make direct communication with amateur stations extremely beneficial to persons on board the vessel or to the person(s) responsible for the scientific research or expedition for which the vessel is to be used.

§ 8.67 **Communication with foreign amateur stations.**—Under the provisions of section 8.66, communication with amateur stations of foreign countries shall be limited to communications with such stations as are authorized to communicate with the ship station concerned; in addition, the nature of the communications exchanged with foreign amateur stations shall be in accordance with the International General Radio Regulations and in conformity with the regulations of the foreign administration having jurisdiction over the amateur station(s) involved.

§ 8.68 **Authorized emission.**—(*a*) Ship telephone stations are authorized to use A–3 emission for the transmission of speech only; in addition, these stations may use types A–1 and A–2 emission for calling, for brief testing, for the transmission of brief service messages, and for communication in an emergency involving the safety of life and property.

(*b*) A–2 or A–3 emission [32] (amplitude modulation) may be used on any authorized operating frequency.[33] Frequency modulation, corresponding to A–2 or A–3 emission [34] may be used on any authorized operating frequency within the band 30,000 to 40,000 kilocycles only.

(*c*) When frequency modulation is used, the total frequency swing arising from modulation shall not exceed 75 percent of the frequency separation band width.

§ 8.69 **Use of A–4 or special emission.**—Upon application, a ship station may be granted authority to use type A–4 or special emission [35] or type A–3 emission for the transmission of addressed program material, on a secondary basis: *Provided,* The applicant makes a satisfactory showing of the need for such type of emission and upon condition that no increase in interference to the service of other stations will result.

§ 8.70 **Points of communication.**—Unless otherwise specified in the license, a ship station is authorized to communicate with coastal stations and maritime mobile stations, without regard to the country to which these stations belong.

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[31] Operation of the lifeboat radio transmitting equipment will be specifically authorized by the regular ship station license when it has been described in the application for such license.

[32] See sec. 2.201, pt. 2, General Rules and Regulations.

[33] See sec. 2.1, pt. 2, General Rules and Regulations.

[34] See sec. 2.201, pt. 2, General Rules and Regulations.

[35] Special emission for the purpose of this section means any emission not meeting the definition of A–1, A–2, A–3, A–4, or B emission given in art. 5, sec. 1, of the International General Radio Regulations. See sec. 2.201 of pt. 2.

§ 8.71 **Operating power.**—(*a*) *Operating power, computation of.*—The operating power shall be computed by one of the following methods: (1) By indirect measurement from the plate input power of the final radio stage, by multiplying the plate voltage by the total plate current of the final radio stage, and by a factor which is specified in the regulations governing the class of station concerned. (2) By direct measurement of the antenna input power. (3) By measurements of field intensity as specified by the regulations governing the class of station concerned.

(*b*) *Operating power tolerance.*—The operating power of all radio stations shall be maintained within the following tolerance of the authorized or licensed power: (1) When the maximum power only is specified, the operating power shall not be greater than necessary to carry on the service and in no event more than 5 percent above the maximum power specified. (2) When an exact power is specified, the operating power shall at all times be within the limits of 105 percent and 90 percent of the maximum power specified.

§ 8.72 **Portable-mobile stations.**—Upon formal application being made and duly executed, including a supplemental statement in reference to conditions (*a*) and (*b*) hereinafter specified, the Commission may grant a license, modification of license, renewal of license, or special temporary authority, permitting operation of a portable-mobile station on board a ship or ships of the United States provided the applicant makes a satisfactory showing that:

(*a*) The services to be rendered will be ship service [36] and the station will be operated as a ship station in conformity with all rules of the Commission which are applicable to the ship service.

(*b*) Unusual circumstances exist whereby a portable-mobile station license is necessary to eliminate the necessity of frequently filing applications for special temporary authority, licenses, or modifications of license in order to permit on short notice the temporary operation of specified equipment on board a designated ship or ships of the United States.

§ 8.73 **Special provisions for portable-mobile stations.**—Advance notice in writing [37] shall be given by the licensee of a portable-mobile station authorized to be operated on board a ship or ships to the Commission prior to any operation contemplated on board a particular vessel and shall state the call letters of the station, name of licensee, approximate date(s) of intended operation on board the designated ship, and the geographical area in which the ship is intended to be navigated. A portable-mobile station authorized to be operated on board ships shall not be retained on board any one vessel during any continuous period exceeding three months without giving further notice to the Secretary of the Commission: *Provided,* That the foregoing requirements shall not apply to operation of a portable-mobile station on board small boats (tenders, dories, lifeboats, etc.), which are regularly associated with a larger vessel, when such portable-mobile station is specifically identified in the license of such larger vessel.

§ 8.74 **License, simultaneous modification and renewal.**—When an application is granted by the Commission necessitating the issuance of a modified license less than 60 days prior to the expiration date of the license sought to be modified, and an application for renewal of said license is granted subsequent or prior thereto (but within 30 days of expiration of the present license) the modified license as well as the renewal license shall be issued to conform to the combined action of the Commission.

§ 8.80 **Type B emission prohibited.**—No license shall be issued for the operation of any station using, or proposing to use, transmitting apparatus employing damped wave (Type B) emission, except for the operation of lifeboat apparatus for routine tests and emergency communication in the open sea.

§ 8.82 **Calling and distress frequencies**—(*a*) The international calling and distress frequency is 500 kilocycles. The provisions of the International General Radio Regulations pertaining to the international calling and distress frequency 500 kilocycles shall apply in the Great Lakes region.

(*b*) The interim United States high frequency calling and distress frequency is 8280 kilocycles. The provisions governing the use of 8280 kilocycles shall apply to all areas.

§ 8.83 **Use of distress frequencies.**—(*a*) The international calling and distress frequency 500 kilocycles shall be used by ship stations and aircraft stations in requesting help from the maritime service. Ship stations and aircraft stations which are either unable to use this frequency effectively or wish to obtain further assistance, shall use the interim United States distress frequency 8280 kilocycles. These frequencies may be used only for calls and replies, for distress traffic, urgent and safety messages, and for operating signals.

(*b*) Transmission on these frequencies with the exception of urgent and safety messages and signals, must cease twice each hour, for 3 minutes, beginning at x:15 and x:45 o'clock, Greenwich Civil Time (GCT).

§ 8.84 **Use of other frequencies for distress.**—In case of distress, if it is not possible to use the international distress frequency, any station of the maritime mobile service may use any other frequency available to it to call attention, report the position of the ship or aircraft in distress, and obtain help.

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[36] See sec. 8.21, which defines the term "ship service."

[37] Telegraphic notice may be made where circumstances require.

§ 8.85 **Use of 143 kilocycles and other calling frequencies.**—In no case shall the calling frequencies 143, 500 and 8280 kilocycles be used for working purposes except as may be necessary for the handling of distress, urgent, or safety messages. Other radiotelegraph calling frequencies shall be used primarily for calling and answering; however, they may be used for working purposes subject to the condition that interference is not caused to calls from maritime mobile stations and coastal stations.

§ 8.86 **Use of working frequencies.**—Frequencies above 1500 kilocycles designated in a ship telegraph station license as "working" may also be used for all purposes for which ship telegraph calling frequencies above 1500 kilocycles are authorized.

§ 8.91 **Additional frequencies.**—(*a*) In addition to the frequencies designated in the license of a ship station, such station, when communicating with a coastal station, may transmit:

(1) On any working frequency between 110 and 194 kilocycles when directed to do so by a coastal telegraph station operating in this band, provided no interference results to the service of any other land or fixed station, and provided that on frequencies below 160 kilocycles the emission shall be A-1 only.

(2) On a working frequency within the band 385 to 23,000 kilocycles used by a coastal telegraph station when directed to do so by the coastal station to which the frequency is assigned.

(*b*) In addition to the frequencies designated in the license of a ship station, such station when communicating with a mobile or coastal station of the United States Government, may transmit on a United States Government frequency when authorized or directed to do so by the Government station concerned or by the Government department to which the frequency is assigned. The ship station operating frequency, the type of emission, and the class of traffic on this frequency shall be designated by the Government station: *Provided*, That on frequencies below 160 kilocycles the emission shall be A-1 only.

§ 8.92 **Record of frequency adjustments.**—In ship stations licensed to operate on frequencies within the band 365 to 515 kilocycles, a written record shall be maintained of the adjustments of the transmitting and receiving equipment for operation on the frequencies 375 and 500 kilocycles and at least one working frequency in this band. This record of adjustments shall be posted at all times in a conspicuous place on or near the particular equipment involved.

§ 8.93 **Control of carrier wave in telephony.**—When communicating on 2003, 2182, 2638, 2738, 35,860, or 37,660 kilocycles, the transmitter carrier wave of all ship telephone stations shall be either automatically "voice controlled" or controlled manually by the person whose speech is being transmitted, in order to avoid the transmission of an unmodulated carrier wave.

§ 8.94 **Shared use of 2003, 2638 and 2738 kilocycles.**—(*a*) Any one exchange of communications between any two ship stations on 2003, 2638 or 2738 kilocycles, or between a ship and a coastal station on the frequency 2003 kilocycles or on 2738 kilocycles, shall not exceed 5 minutes in duration after the two stations have established contact by calling and answering. Subsequent to such exchange of communications, neither the frequency 2638 kilocycles nor 2738 kilocycles shall again be used for communication between the same two stations until 15 minutes have elapsed: *Provided*, That this requirement shall in no way limit or delay the transmission of distress or emergency communications.

(*b*) The alternate transmission on 2003 kilocycles, 2638 kilocycles or 2738 kilocycles by each of two ship stations, engaged in any one exchange of signals or communications with each other, shall take place on only one of these frequencies and for this purpose, both stations shall transmit and receive on the same frequency: *Provided*, That this requirement is waived in the event of emergency when by reason of interference or limitation of equipment this method of communication cannot be used.

§ 8.95 **Authorized use of 2003, 2638 and 2738 kilocycles.**—(*a*) The frequencies 2003 and 2738 kilocycles shall be used by ship radio stations solely for the exchange of "distress"[38] and "safety"[39] communications and communications relating directly to the operation of the ship, subject to the priority of communications designated by section 8.42.

(*b*) The frequency 2638 kilocycles shall be used by ship radio stations primarily for the exchange of communications relating to the safety of navigation and to the ship's business. The exchange of any other communications on this frequency is authorized upon the express condition that interference shall not be caused to the handling of messages relating to the safety of navigation and the ship's business, with due regard to the priority of communications designated by section 8.42.

§ 8.97 **Frequency measurement.**[40]—The licensee of each ship station shall provide for measurement of each operating frequency of the station and shall establish a procedure for regular measurement of these frequencies. These measurements shall be made by means independent of the frequency control of the ship station transmitter and shall be of an accuracy sufficient to detect deviations from the assigned frequency within one-half the authorized tolerance.

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[38] For this purpose, "distress" communications are construed to be any communications relative to immediate assistance needed by a ship in distress; i.e., a vessel is threatened by serious and imminent danger and immediate assistance is necessary.

[39] For this purpose, "safety" communications are construed to mean communications concerning the safety of a ship as distinguished from distress, or concerning the safety of a person or persons on board or sighted from on board, and communications concerning the safety of navigation or important meteorological warnings.

[40] Par. 6 (3), art. 9, of the International General Radio Regulations provides that all ship stations transmitting on frequencies in the band 100 to 160 kilocycles and on frequencies above 4000 kilocycles must be equipped with a wavemeter (frequency meter) having a precision at least equal to 0.005 (0.5 percent) when the transmitter itself is

LIFEBOAT INSTALLATIONS

REQUIREMENTS FOR ALL COMPULSORY LIFEBOAT RADIO INSTALLATIONS

§ 8.201 **Inspection and maintenance of lifeboat radio installation.**—(*a*) The lifeboat radio installation shall be inspected and tested[41] by a qualified representative of the licensee within 24 hours prior to departure to sea from each port (except not necessarily more than once each week) and at least once each year with the lifeboat afloat in a harbor or port of the United States. The results of any inspections and tests not made in the inspector's presence shall be made known to the master of the vessel and shall be entered in the ship's radio station log or recorded in the ship's log if the ship is not provided with a radiotelegraph station. The records of all inspections and tests shall be made available to duly authorized representatives of the Commission upon request. The inspection afloat shall include an actual test of the transmitter (and receiver when required) connected to the regular lifeboat antenna erected to determine that each is in effective operating condition. When testing with the lifeboat not afloat, the transmitter may be connected to an artificial antenna.

(*b*) When the vessel is under way, provision shall be made for adequate charging of the storage batteries and the routine inspection of all batteries used to supply the power to lifeboat radio installations. The charging and routine inspection of such batteries shall not require their removal from the lifeboats in which they are installed. The necessary charging equipment shall be arranged so as not to interfere with the launching of the lifeboats, and for this purpose shall be easily and quickly removable. Inspection of the batteries shall be made at least once every seven days by a qualified representative of the licensee, and a statement in regard to the condition and specific gravity in the case of a lead-acid battery, or voltage under normal load in the case of Edison batteries (or dry batteries when such batteries are permitted) shall be reported to the master and entered in the ship's radio station log. Any storage battery provided as a power supply or as a spare power supply shall be kept fully charged at all times.

REGULATION OF WATCH

§ 8.211 **Report to bridge.**—On board a cargo vessel of the United States subject to title III, part II of the Communications Act which is fitted with an auto-alarm, the operator, when going off watch, shall report to the officer on watch on the bridge whether or not the auto-alarm has been placed in use and adjusted for effective operation.

§ 8.212 **Use of auto-alarm.**—(*a*) The auto-alarm shall be in operation, connected to the main antenna, and adjusted for normal efficiency, according to prevailing conditions of radio reception, at all times while the ship is being navigated outside a harbor or port when the operator is not on watch, and shall not be rendered inoperative when a radio direction finder, on board the same ship, is being used.

(*b*) The auto-alarm shall be in operation, connected to the antenna and adjusted for normal efficiency according to prevailing conditions of radio reception, when the ship is being navigated outside a harbor or port and while the operator, when on watch and subject to authority of the master, is engaged over an extended period in receiving time signals, weather reports, hydrographic reports, reports regarding aids to navigation or authorized press material.

§ 8.213 **Auxiliary antenna.**—On a vessel required by law to maintain a watch by a qualified operator or operators, an effective auxiliary antenna or other approved arrangement shall be provided whenever deemed necessary by the Commission, to avoid unauthorized interruption of this watch during use of a radio direction finder on board the same vessel.

RADIO LOG

§ 8.221 **Radio log for safety purposes.**—Each ship station operating on frequencies within the band 100 to 515 kilocycles, when required by law to keep a watch for safety purposes by means of a qualified operator, shall maintain an accurate radio log, as follows:

(*a*) Each sheet of the log shall be numbered in sequence, for each voyage, and shall include official call letters of the ship station and the name of the operator on watch.

(*b*) The entry "on watch" shall be made by the operator beginning a watch, followed by his signa-

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incapable of being adjusted with this precision or better. For this purpose, the Commission will accept a master-oscillator of a ship station electron tube transmitter in lieu of the frequency meter prescribed by this international regulation, provided the calibration of the said transmitter and of the circuit as a whole is such as to permit the convenient adjustment of the transmitter to its licensed frequencies within the tolerance for ship stations prescribed by section 8.96.

[41] Subject to such limitations as may be imposed by United States Naval Authority or by foreign governments at foreign ports. It is necessary that each lifeboat transmitter be licensed by the Commission to insure compliance with the Rules and Regulations of the Commission, during the required tests with an actual antenna. Operation of a lifeboat transmitter is ordinarily authorized by the regular ship station license when it has been described in the application for such license and the authorization has been approved by the Commission.

ture. The entry "off watch" shall be made by the operator being relieved or terminating a watch, followed by his signature. All log entries shall be currently completed at the end of each watch by the operator responsible for the entries. The use of initials or signs is not authorized in lieu of the operator's signature.

(*c*) During the period a watch is maintained by an operator, all calls transmitted to or from the ship station and all replies transmitted or received shall be entered, stating the time and frequencies, and the call letters[42] of the station communicated with or heard. In addition, a notation of any messages exchanged shall be entered, stating the time, the frequency in kilocycles, and the call letters[43] of the station(s) heard, or communicated with. Insofar as possible, a positive entry with respect to reception on 500 kilocycles shall be made at least once in each 15 minutes. The entries required by paragraph (*e*) hereof shall be acceptable, as positive entries provided operating conditions are such as to prevent additional entries being made.

(*d*) The time of making an entry shall be shown opposite the entry and shall be expressed in Greenwich mean time (GMT), except that in the Great Lakes region the time shall be expressed in eastern standard time (EST) (counted from 00:00 to 24:00 o'clock, beginning at midnight).[44] The first entry in each hour shall consist of four figures; additional entries in the same hour may be expressed in two figures by omitting the hour designation. The abbreviation "GMT" (EST in the Great Lakes region) shall be marked at the head of the column in which the time is entered.

(*e*) During the period a watch is maintained by an operator, an entry shall be made twice per hour stating whether or not the international silent period was observed. In addition, entries shall be made indicating any signals or communications heard on 500 kilocycles during this period. If no signals are heard on 500 kilocycles an entry to that effect shall be made. The use of rubber stamps for making entries to show observation of the silent period is not authorized.

(*f*) All distress calls, automatic alarm signals, urgent and safety signals made or intercepted, the complete text, if possible, of distress messages and distress communications, and any incidents or occurrences which may appear to be of importance to safety of life or property at sea, shall be entered, together with the time of such observation or occurrence, and the position of the ship or other mobile unit in need of assistance, if it can be determined.

(*g*) Whenever harmful interference is experienced, an entry shall be made to that effect, stating the source of the interference, if known.

(*h*) The approximate geographical location of the ship, preferably the noon position, shall be entered each day of each voyage, either in terms of latitude and longitude, or as the distance in nautical miles and the direction from a known fixed point. For this purpose, the master of the ship shall furnish this information to the radio operator. The position report so furnished shall correspond to any entry of the same position made in other official records of the ship.

(*i*) An entry shall be made of the time of departure and arrival of the vessel at each port, including in each entry the name of the port.

(*j*) On a cargo vessel equipped with an auto-alarm, the entry "auto-alarm on," "sensitivity set at ...."[45] and the entry "auto-alarm off," respectively, shall be made whenever the operator places the auto-alarm in and out of operation. Results of the required auto-alarm tests shall be entered daily, including the sensitivity-control setting and the minimum number of 4-second dashes from the testing device which were necessary to properly operate the alarm.

(*k*) On a cargo vessel equipped with an auto-alarm, an entry shall be made in the radio station log whenever the visual indicator installed on the bridge (to indicate when the alarm becomes inoperative due to prolonged atmospherics or other interference), remains actuated for a continuous period of 5 minutes. A statement shall be included giving particulars as to the time the operator was called to make the necessary repairs or adjustments; any reason for the failure; the names of any parts removed, added, or substituted; repairs effected; and the time the alarm was restored to proper operating conditions.

(*l*) On a cargo vessel equipped with an auto-alarm, an entry shall be made in the radio station log whenever the auto-alarm becomes inoperative due to causes not indicated by the audible warning or the visual indicator, or whenever the audible warning is actuated. The entry shall include a statement showing the time the operator was called to make any necessary repairs or adjustments; the reason for the audible alarm being actuated or failing to be actuated, any parts removed, added, or substituted; repairs effected; and the time the auto-alarm was restored to proper operating condition.

(*m*) Entries shall be made of the results of tests of the emergency installation including transmitter antenna current, hydrometer readings of lead-acid storage batteries, voltage readings of other types of batteries, and quantity of fuel available for engine generators.

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[42] If desired, the names of the stations or ships also may be entered.

[43] As amended by the Commission, effective November 14, 1939.

[44] For example, 8:01 p.m. eastern standard time would be entered as 0001 GMT; 8:30 a.m. eastern standard time would be entered as 1230 GMT; 7:45 p.m. eastern standard time would be entered as 2345 GMT.

[45] The actual setting of the sensitivity control at the time the auto-alarm is placed in operation should be designated.

(*n*) An entry shall be made each time the emergency power supply is used (when the vessel is in the open sea) to carry on routine communication (other than a watch for safety purposes), stating the approximate period of time of such use.

(*o*) Results of inspections and tests of lifeboat radio equipment, when installed in compliance with requirements of law, prior to departure of the vessel from a harbor or port and the results of weekly inspections [46] of such lifeboat equipment shall be entered.

(*p*) A daily entry shall be made regarding comparison of the radio station clock with standard time, including an indication of any errors observed and corrections made. For this purpose, authentic radio time signals received from land or fixed stations shall be acceptable as standard time.

(*q*) Any failure of equipment to operate as required, any failure of power supply, any inability to obtain sufficient power to charge storage batteries or to properly operate the radio installation and any incidents tending to unduly delay communication shall be entered.

(*r*) All test transmissions shall be entered, together with the time of such transmissions and the approximate geographical location of the vessel, without regard to whether two-way communication with any other station is established.

§ 8.222 **Radio log during hours of service.**—(*a*) Each ship station, not required by law to keep a watch for safety purposes, but authorized to operate on frequencies within the band 100 to 515 kilocycles, shall maintain an accurate radio log in accordance with paragraphs (*a*) to (*i*), inclusive, of section 8.221, during its hours of service when operating on frequencies within this band. The radio log of such stations shall also contain the entries prescribed by paragraphs (*p*) and (*r*) of section 8.221.

(*b*) Each ship station authorized to operate on any frequency or frequencies within the band 3000 to 30,000 kilocycles (except ship stations on the Great Lakes and on board vessels navigated solely on inland waters of the United States) shall maintain an accurate radio log, when operating on frequencies within this band, in accordance with paragraphs (*a*), (*b*), (*d*), (*f*), (*g*), (*h*), (*i*), (*p*), (*q*) and (*r*) of section 8.221.

(*c*) Each ship station (except ship stations on the Great Lakes and on board vessels navigated solely on inland waters of the United States) which is authorized to operate on any frequency within the band 1500 to 3000 kilocycles or in any band above 30,000 kilocycles, shall maintain an accurate log, when operating on any frequency within these bands, as follows:

(1) Each sheet of the log shall be numbered in sequence and shall include official call letters of the ship station and the name of the licensed operator in attendance at the time communication is effected.

(2) An entry shall be made for each complete exchange of communications with any station, stating the approximate geographical location of vessel, the call letters and the name of the station communicated with, the time of the communication, and the nature of the messages or signals exchanged.

(3) All test transmissions shall be entered, together with the time of such transmissions and the approximate geographical location of the vessel, without regard to whether two-way communication with any other station is established.

(4) All distress calls, urgent and safety signals made or intercepted; the complete text, if possible, of distress messages and distress communications; and any incidents or occurrences which may appear to be of importance to safety of life or property at sea, shall be entered, together with the time of such observation or occurrence, and the position of the ship or other mobile unit in need of assistance, if it can be determined.

(5) The time of making an entry shall be shown opposite the entry and shall be expressed in Greenwich mean time (GMT) (counted from 00:00 to 24:00 o'clock, beginning at midnight).[47] The first entry in each hour shall consist of four figures; additional entries in the same hour may be expressed in two figures by omitting the hour designation. The abbreviation "GMT" shall be marked at the head of the column in which the time is entered.

(6) Any failure of equipment to operate as required, any failure of power supply, any inability to obtain power to charge storage batteries or to properly operate the radio installation and any incidents tending to unduly delay communication shall be entered.

(*d*) Each ship station on the Great Lakes and on board a vessel navigated solely on inland waters of the United States which is authorized to operate on any frequency or frequencies above 550 kilocycles shall maintain an accurate log when operating on such frequencies, as follows:

(1) Each sheet of the log shall be numbered in sequence and shall include official call letters of the ship station and the signature of the licensed operator in attendance at the time communication is effected.

(2) An entry shall be made for each complete exchange of communications with any station, stating the approximate geographical location of the vessel, the call letters and the name of the station communicated with, the time of the communication, and the nature of the messages or signals exchanged, and the designation of the transmitting frequencies.

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[46] See sec. 8.201.

[47] For example, 8:01 p.m. eastern standard time would be entered as 0001 GMT; 8:30 a.m. eastern standard time would be entered as 1230 GMT; 7:45 p.m. eastern standard time would be entered as 2345 GMT.

(3) All test transmissions shall be entered, including designation of the transmitting frequency, together with the time of commencement and completion of such transmissions and the approximate geographical location of the vessel, without regard to whether two-way communication with any other station is established.

(4) All distress calls, urgent and safety signals made or intercepted; the complete text, if possible, of distress messages and distress communication; and any incidents or occurrences which may appear to be of importance to safety of life or property at sea, shall be entered, together with the time of such observation of occurrence, and the position of the ship or other mobile unit in need of assistance, if it can be determined.

(5) Any failure of equipment to operate as required, any failure of power supply, any inability to obtain power to charge storage batteries or to properly operate the radio installation and any incidents tending to unduly delay communication shall be entered.

(6) The time of making an entry shall be shown opposite the entry and shall be expressed as follows:

For vessels navigated on the Great Lakes:

Eastern standard time (EST) counted from 00:00 to 24:00 o'clock, beginning at midnight. The first entry in each hour shall consist of four figures; additional entries in the same hour may be expressed in two figures by omitting the hour designation. The abbreviation "EST" shall be marked at the head of the column in which the time is entered.

For vessels navigated on inland waters of the United States, other than the Great Lakes:

Local standard time (EST, CST, etc.) (counted from 00:00 to 24:00 o'clock, beginning at midnight).[48] The first entry in each hour shall consist of four figures; additional entries in the same hour may be expressed in two figures by omitting the hour designation. The abbreviation "EST" or "CST," etc., shall be marked at the head of the column in which the time is entered. However, this provision shall not prohibit the use of time entries expressed in GMT (and so indicated) in lieu of local standard time.

§ 8.223 **Disposition of logs.**—Ship station logs shall be fully completed at the end of each voyage and before the operator(s) responsible leave(s) the ship. The radio log currently in use shall be kept by the licensed operator(s) of the station and during use shall be located in the radio operating room of the vessel. At the conclusion of each voyage terminating at a port of the United States,[49] the original radio log (or a duplicate thereof)[50] dating from the last departure of the vessel from a United States port shall be retained under proper custody on board the vessel for a sufficient period of time (not required to be retained for more than 24 hours) to be available for inspection by duly authorized representatives of the Commission. Thereafter, the original log (and the duplicate log, if provided) may be filed at an established shore office of the ship station licensee, and shall be retained as stipulated by section 8.224.

§ 8.224 **Retention of radio station logs.**—Logs of a radio station shall be retained by the licensee for a period of one year: *Provided, however,* That logs involving communications incident to a disaster or which include communications incident to or involved in an investigation by the Commission and concerning which the licensee has been notified, shall be retained by the licensee until he is specifically authorized in writing by the Commission to destroy them; *Provided, further,* That logs incident to or involved in any claim or complaint of which the licensee has notice shall be retained by the licensee until such claim or complaint has been fully satisfied or until the same has been barred by statute limiting the time for the filing of suits upon such claims.

AUXILIARY EQUIPMENT, TOOLS, AND SPARE PARTS

§ 8.231 **General.**—On board all vessels subject to title III, part II of the Communications Act, sufficient tools to make any minor adjustments of the main and emergency radio installation shall be provided, together with spare parts and auxiliary equipment sufficient to maintain the installation in efficient working condition. These spare parts and this auxiliary equipment shall be located so as to be readily accessible to the radio operator in an emergency.

§ 8.232 **Necessary spare parts.**—The following spare parts (for radio equipment, other than auto-alarm and radio-equipped lifeboats) are considered indispensable for the maintenance of the appropriate installations in efficient working condition on board vessels subject to title III, part II of the Communications Act:

(*a*) Sufficient wire of good electrical conductivity and suitable insulators for the erection of a single-wire antenna of the same configuration and linear dimensions as the main transmitting antenna but not less than 300 feet of such wire and not less than two such insulators; or an assembled single-wire transmitting antenna (including suitable insulators) of the same linear dimensions as the main transmitting antenna.

(*b*) One sleeve bearing of each type used by all rotating machinery which is a component part of the radio installation required by law.

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[48] For example, 7:01 p.m. eastern standard time would be entered as 1901 EST; 7:30 a.m. eastern standard time would be entered as 0730 EST; 6:45 p.m. eastern standard time would be entered as 1845 EST.

[49] Includes Hawaii, Alaska, Puerto Rico, and the Virgin Islands.

[50] Duplicate logs are not required by the provisions of this section, unless the original log is removed prior to opportunity for official inspection, as explained.

(*c*) One complete set of brushes for each unit of rotating machinery which utilizes brushes.

(*d*) Renewable fuse-cartridges of each type used in connection with units of the radio installation in the amount of at least one-half the number of each size and type in actual use. For each renewable fuse-cartridge in actual use, there shall be available six spare fuse links of appropriate capacity. For each nonrenewable fuse in use, there shall be available six spare fuses of the same type and of appropriate capacity.

(*e*) One spare electric light bulb for each emergency light required by section 8.115 (*j*).

§ 8.233 **Necessary auxiliary equipment.**—The following auxiliary equipment (for radio installation, other than auto-alarm and radio-equipped lifeboats) is considered indispensable for the maintenance of the appropriate installations in efficient working condition on board vessels subject to title III, part II of the Communications Act.

(*a*) One 1- to 2-inch screwdriver with approximately ⅛-inch blade.

(*b*) One 4- to 6-inch screwdriver.

(*c*) One set of assorted end wrenches or socket wrenches, or one adjustable end wrench.

(*d*) One pair 5- to 8-inch side-cutting pliers.

(*e*) One high-resistance direct-current voltmeter having a resistance of at least 1000 ohms per volt and capable of measuring 2, 6, and 110 volts with an accuracy of at least 3 percent except that on ships where the normal radio room power supply voltage is higher than 110 to 120 volts direct current, the voltmeter shall be capable of measuring this line voltage and 2 and 6 volts with an accuracy of at least 3 percent.

(*f*) One electric flashlight, two-cell or larger, complete with bulb and battery, or one portable emergency electric lamp (protected from mechanical injury) with at least 10 feet of flexible cord and means for rapid connection to the emergency source of power. One spare bulb of the type used shall be provided.

(*g*) One hydrometer for use with lead-acid batteries when this type of battery is used.

(*h*) One gallon of distilled water or other water suitable for use in storage batteries.

(*i*) Instruction book(s) and circuit diagrams, including modifications, covering transmitter(s), receiver(s), and direction finder, if a direction finder is required.

§ 8.234 **Additional spare parts for specific equipment.**—In addition to the spare parts required by section 8.232, and the auxiliary equipment required by section 8.233, spare parts as are specifically designated in special lists [51] promulgated by the Commission pursuant to the provisions of section 356 (a) (2) of the Communications Act shall be provided for transmitters, receivers, and direction finders which have been given type approval by the Commission.

§ 8.235 **Additional spare parts in general.**—Prior to the Commission's approval of a particular type of marine transmitter, receiver, or direction finder, and prior to the issuance of associated specific lists of required spare parts and auxiliary equipment, the following spare parts and auxiliary equipment shall be required in addition to those stipulated in sections 8.232 and 8.233.

(*a*) *Tube transmitters* (*spare parts only*).—(1) One radio-frequency oscillator tube, one tube for each radio-frequency amplifier stage, and, if used to provide A–2 emission, one audio-frequency oscillator tube. One tube for a main transmitter or two tubes for an emergency transmitter intended for use in the radio-frequency circuit of transmitters of the self-rectified, simple oscillator type. Two anode power-supply rectifier tubes, if used.

(2) One resistor of each type used as a grid leak; one resistor of each type as used in voltage divider of grid-blocking keying circuit; one resistor of each type as used in series with keying relay winding. The value of each resistor shall be clearly indicated thereon.

(*b*) *Receivers* (*spare parts*).—(1) One complete set of tubes for the receiver(s).

(2) One pair of head telephones complete with connecting cord and, if used, a cord-terminal plug.

(*c*) *Direction finders* (*spare parts*).—(1) One complete set of tubes for the receiver associated with the direction finder, if a direction finder is required.

(*d*) *Radio-equipped lifeboats* (*auxiliary equipment*).—(1) One screwdriver.

(2) One pair of side-cutting pliers.

(*e*) *Radio-equipped motor lifeboats of passenger vessels navigated in the open sea* (*spare parts*).—(1) At least 35 feet of insulated wire suitable for use as antenna wire.

(2) Two antenna insulators.

(3) One artificial antenna capacitor.

(4) Two tubes for radiotelegraph transmitters, except when transmitter employs a single transmitting tube, in which case one tube is required.

(5) One complete set of tubes for the radiotelegraph receiver.

(6) One panel electric light bulb, if used.

(7) Renewable fuse-cartridges of each type used in connection with the units of the lifeboat radio installation in the amount of at least one-half the number of each size and type in actual use. For each renewable fuse-cartridge in actual use, there shall be available six spare fuse links of appropriate capacity. For each renewable fuse-cartridge in actual use, there shall be available six spare fuse

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[51] Lists of spare parts required for specific types of equipment approved by the Commission are furnished to its inspectors in charge at principal ports and are available to others upon request.

links of appropriate capacity. For each nonrenewable fuse in use, there shall be available six spare fuses of the same type and of appropriate capacity. If fuse wire is used, sufficient wire shall be provided to permit six complete fuse replacements.

(*f*) *Optional lifeboat radio installations provided in accordance with Section 8.205 for use in lifeboats* (*spare parts*).—(1) One electron tube of each type used for normal operation of the radio installation in accordance with the requirements governing the installation, including neon or any other type of tube or lamp employed as resonance indicator(s).

(2) Six fuses of each type used which shall be of the same rating and interchangeable therewith;

(3) Where a kite and balloon are used for an antenna support, one spare 300-foot length of antenna wire of the type used which shall be of the same rating and interchangeable therewith.

§ 8.236 **Spare parts and auxiliary equipment for auto-alarm, if auto-alarm is required.**—

(*a*) *Radiomarine Corporation of America Model AR-8600 and Model AR-8600-X.*—

(1) Tubes: One type 6H6, one type 6A8, two type 6K7, five type 1611.

(2) Two bridge warning-light bulbs.

(3) One 30-ohm resistor.

(4) One 9-volt dry cell bias battery.

(5) Nine glass-enclosed 6-ampere fuses, six glass-enclosed ½-ampere fuses, six 10-ampere fuse links for cartridge-type fuses, two cartridges for 10-ampere fuse links.

(6) One relay contact burnishing tool.

(*b*) *Radiomarine Corporation of America Model AR-8601.*—

(1) Tubes: One type 6H6, one type 6A8, two types 6K7, five type 1611.

(2) Two bridge warning-light bulbs.

(3) One 80-ohm resistor.

(4) One 9-volt dry cell bias battery.

(5) Six glass-enclosed ½-ampere fuses, 6 glass-enclosed 6-ampere fuses, twelve 6-ampere fuse links for cartridge-type fuses, one cartridge for 6-ampere fuse links, twelve 10-ampere fuse links for cartridge-type fuses, one cartridge for 10-ampere fuse links.

(6) One relay contact burnishing tool.

(7) One spare charging resistor.

(*c*) *Mackay Radio & Telegraph Co., types 101-A and 101-B.*—

(1) Tubes: For the type 101-A alarm: One type 6D6, one type 89, three type 76.

For the type 101-B alarm: One type 6D6, one type 89, one type 75, and two type 76.

(2) Two bridge warning-light bulbs.

(3) Two commutating brushes, two governor brushes, and two brush springs for selector motor.

(4) Six 1-ampere fuses for receiver power supply unit, three cartridges for 6-ampere fuse links, one cartridge for 3-ampere fuse links, nine 6-ampere fuse links for cartridge-type fuses, three 3-ampere fuse links for cartridge-type fuses.

(5) One 4½-volt dry cell bias battery.

(6) One relay contact burnishing tool.

(*d*) *Mackay Radio and Telegraph Company, Type 5001-A.*—

(1) Electron tubes: One type 6D6, one type 6SR7, one type 89, two type 76 and one type OA3/VR75.

(2) One 60 watt 120 volt ballast lamp.

(3) Two bridge warning-light bulbs.

(4) Two pilot lamps.

(5) Nine 2 ampere fuses.

(6) Two motor commutator brushes, two governor brushes, and four brush springs for selector motor.

(7) One relay contact burnishing tool.

(8) One set-screw wrench.

(9) One 4½ volt dry cell bias battery.

§ 8.237 **Location of spare parts.**—(*a*) Spare parts for the direction finder receiver as required by section 8.235, paragraph (c), shall be kept in the same compartment or room in which this receiver is located.

(*b*) Spare parts and auxiliary equipment for the radio-equipped lifeboat, as required by section 8.235, paragraph (*e*), shall be kept in the lifeboat cabin housing the radio equipment.

(*c*) The spare emergency light bulb(s) as required by section 8.232, paragraph (*c*), shall be mounted in close proximity to the corresponding emergency light socket(s).

(*d*) The antenna wire, antenna insulators, and distilled water, as required by sections 8.232, paragraph (*a*), and 8.233, paragraph (*h*), respectively, may be retained in the radio operating room or elsewhere, provided the antenna material is readily accessible to the radio operator in an emergency.

(*e*) All other spare parts and auxiliary equipment shall be securely retained preferably in a single space, readily accessible to the radio operator in an emergency, in the main radiotelegraph operating room, or, if desired, in any associated room adjacent to and connected with the main radiotelegraph operating room by an interconnecting doorway.

(*f*) The space(s) allocated for the location of spare parts and auxiliary equipment in accordance with paragraph (*e*) herein shall be used only for this purpose, and such space(s) shall be appropriately and conspicuously marked.

(g) All required spare parts and auxiliary equipment shall be available for observation by authorized representatives of the Commission at the time of inspection of the ship radio installation.

INSPECTIONS

§ 8.251 **Station available for inspection.**—Pursuant to section 303 (n) ot the Communications Act, the radio installation on board any ship of United States registry, or on board any foreign ship within the territorial jurisdiction of the United States, shall be available for inspection by duly authorized representatives of the Commission at any reasonable time and at such frequent intervals as within the discretion of the Commission will insure compliance with applicable regulations, laws, and treaties.

§ 8.252 **Application for inspection.**—Pursuant to section 360 (b) of the Communications Act, the vessel owner, vessel operator, ship station licensee, and master of a vessel of United States registry which is subject to the provisions of title III, part II of the Communications Act shall be jointly responsible for the submission of a formal application to the Commission [52] at least once in each 12-month period for a detailed inspection of the ship radio installation. This application shall be filed at least 10 days prior to the date on which the radio installation of the vessel will be ready for inspection at the location specified in the application. A service representative of the ship station licensee and sufficient personnel to lower and raise the antenna(s) and to launch the radio-equipped lifeboat(s) shall be on board at the time inspection of the radio installation is desired.

RULES GOVERNING STANDARD AND HIGH-FREQUENCY BROADCAST STATIONS

Rules Governing Standard Broadcast Stations

DEFINITIONS [53]

§ 3.1 **Standard broadcast station.**—The term "standard broadcast station" means a station licensed for the transmission of radiotelephone emissions primarily intended to be received by the general public and operated on a channel in the band 550–1600 kilocycles, inclusive.

§ 3.2 **Standard broadcast band.**—The term "standard broadcast band" means the band of frequencies extending from 550–1600 kilocycles, inclusive, both 550 kilocycles and 1600 kilocycles being the carrier frequencies of broadcast channels.

§ 3.3 **Standard broadcast channel.**—The term "standard broadcast channel" means the band of frequencies occupied by the carrier and two side bands of a broadcast signal with the carrier frequency at the center. Channels shall be designated by their assigned carrier frequencies. Carrier frequencies assigned to standard broadcast stations shall begin at 550 kilocycles and be in successive steps of 10 kilocycles.

§ 3.4 **Dominant station.**—The term "dominant station" means a class I station, as hereinafter defined, operating on a clear channel.

§ 3.5 **Secondary station.**—The term "secondary station" means any station except a class I station operating on a clear channel.

§ 3.6 **Daytime.**—The term "daytime" means that period of time between local sunrise and local sunset.

§ 3.7 **Nighttime.**—The term "nighttime" means that period of time between local sunset and 12 midnight local standard time.

§ 3.8 **Sunrise and sunset.**—The terms "sunrise and sunset" mean, for each particular location and during any particular month, the average time of sunrise and sunset as specified in the license of a broadcast station. (For tabulation of average sunrise and sunset times for each month at various points in the United States, see "Average Sunrise and Sunset Times.")

§ 3.9 **Broadcast day.**—The term "broadcast day" means that period of time between local sunrise and 12 midnight local standard time.

§ 3.10 **Experimental period.**—The term "experimental period" means that time between 12 midnight and local sunrise. This period may be used for experimental purposes in testing and maintaining apparatus by the licensee of any standard broadcast station on its assigned frequency and with its authorized power, provided no interference is caused to other stations maintaining a regular operating schedule within such period. No station licensed for "daytime" or "specified hours" of operation may broadcast any regular or scheduled program during this period.

§ 3.11 **Service areas.**—(*a*) The term "primary service area" of a broadcast station means the area in which the ground wave is not subject to objectionable interference or objectionable fading.

(*b*) The term "secondary service area" of a broadcast station means the area served by the sky wave and not subject to objectionable interference. The signal is subject to intermittent variations in intensity.

(c) The term "intermittent service area" of a broadcast station means the area receiving service from the ground wave but beyond the primary service area and subject to some interference and fading.

§ 3.12 **Main studio.**—The term "main studio" means, as to any station, the studio from which the majority of its local programs originate, and/or from which a majority of its station announcements are made of programs originating at remote points.

§ 3.13 **Portable transmitter.**—The term "portable transmitter" means a transmitter so constructed that it may be moved about conveniently from place to place, and is in fact so moved about from time to time, but not ordinarily used while in motion. In the standard broadcast band, such a transmitter is used in making field intensity measurements for locating a transmitter site for a standard broadcast station. A portable broadcast station will not be licensed in the standard broadcast band for regular transmission of programs intended to be received by the public.

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[52] Applications should be filed with the Engineer in charge, Federal Communications Commission, at the Field Division office nearest the desired port of inspection of the vessel.

[53] Other definitions which may pertain to standard broadcast stations are included in section 2.1 and the Communications Act of 1934, as amended.

§ 3.14 **Auxiliary transmitter.**—The term "auxiliary transmitter" means a transmitter maintained only for transmitting the regular programs of a station in case of failure of the main transmitter.

§ 3.15 **Technical definitions.**—(*a*) *Combined audio harmonics.*—The term "combined audio harmonics" means the arithmetical sum of the amplitudes of all the separate harmonic components. Root sum square harmonic readings may be accepted under conditions prescribed by the Commission.

(*b*) *Effective field.*—The term "effective field" or "effective field intensity" is the root-mean-square (RMS) value of the inverse distance fields at a distance of 1 mile from the antenna in all directions in the horizontal plane.

(*c*) *Operating power.*—"Operating power" is the power that is actually supplied to the radio station antenna.

(*d*) *Maximum rated carrier power.*—"Maximum rated carrier power" is the maximum power at which the transmitter can be operated satisfactorily and is determined by the design of the transmitter and the type and number of vacuum tubes used in the last radio stage.

(*e*) *Plate input power.*—"Plate input power" means the product of the direct plate voltage applied to the tubes in the last radio stage and the total direct current flowing to the plates of these tubes, measured without modulation.

(*f*) *Antenna power.*—"Antenna input power" or "antenna power" means the product of the square of the antenna current and the antenna resistance at the point where the current is measured.

(*g*) *Antenna current.*—"Antenna current" means the radio-frequency current in the antenna with no modulation.

(*h*) *Antenna resistance.*—"Antenna resistance" means the total resistance of the transmitting antenna system at the operating frequency and at the point at which the antenna current is measured.

(*i*) *Modulator stage.*—"Modulator stage" means the last amplifier stage of the modulating wave which modulates a radio-frequency stage.

(*j*) *Modulated stage.*—"Modulated stage" means the radio-frequency stage to which the modulator is coupled and in which the continuous wave (carrier wave) is modulated in accordance with the system of modulation and the characteristics of the modulating wave.

(*k*) *Last radio stage.*—"Last radio stage" means the oscillator or radio-frequency-power amplifier stage which supplies power to the antenna.

(*l*) *Percentage modulation (amplitude).*—"Percentage modulation" with respect to an amplitude modulated wave means the ratio of half the difference between the maximum and minimum amplitudes of the amplitude modulated wave to the average amplitude expressed in percentage.

(*m*) *Maximum percentage modulation.*—"Maximum percentage of modulation" means the greatest percentage of modulation that may be obtained by a transmitter without producing in its output harmonics of the modulating frequency in excess of those permitted by these regulations.

(*n*) *High level modulation.*—"High level modulation" is modulation produced in the plate circuit of the last radio stage of the system.

(*o*) *Low level modulation.*—"Low level modulation" is modulation produced in an earlier stage than the final.

(*p*) *Plate modulation.*—"Plate modulation" is modulation produced by introduction of the modulating wave into the plate circuit of any tube in which the carrier frequency wave is present.

(*q*) *Grid modulation.*—"Grid modulation" is modulation produced by introduction of the modulating wave into any of the grid circuits of any tube in which the carrier frequency wave is present.

EQUIPMENT

§ 3.41 **Maximum rated carrier power; tolerances.**—The maximum rated carrier power of a standard broadcast transmitter shall not be less than the authorized power nor shall it be greater than the value specified in the following table:

Class of Station	Maximum Power Authorized to Station	Maximum Rated Carrier Power Permitted to be Installed*
		Watts
Class IV.... .	100 or 250 watts	250
Class III......	500 or 1,000 watts	1,000
	5,000 watts	5,000
Class II...	250, 500, or 1,000 watts	1,000
	5,000 or 10,000 watts	10,000
	25,000 or 50,000 watts	50,000
Class I	10,000 watts	10,000
	25,000 or 50,000 watts	50,000

* The maximum rated carrier power must be distinguished from the operating power. (See section 3.15.)

§ 3.42 **Maximum rated carrier power; how determined.**—The maximum rated carrier power of a standard broadcast transmitter shall be determined as the sum of the applicable power ratings of the vacuum tubes employed in the last radio stage.

(*a*) The power rating of vacuum tubes shall apply to transmitters employing the different classes of operation or systems of modulation as specified in Power Rating of Vacuum Tubes prescribed by the Commission.

(*b*) If the maximum rated carrier power of any broadcast transmitter, as determined by paragraph (*a*) of this section, does not give an exact rating as recognized in the Commission's plan of allocation, the nearest rating thereto shall apply to such transmitter.

(*c*) Authority will not be granted to employ, in the last radio stage of a standard broadcast transmitter, vacuum tubes from a manufacturer or of a type number not listed until the manufacturer's rating for the class of operation or system of modulation is submitted to and approved by the Commission. These data must be supplied by the manufacturer in accordance with Requirements for the Approval of the Power Rating of Vacuum Tubes, prescribed by the Commission.

§ 3.43 **Changes in equipment; authority for.**—No licensee shall change, in the last radio stage, the number of vacuum tubes to vacuum tubes of different power rating or class of operation, nor shall it change system of modulation without the authority of the Commission.[54]

§ 3.44 **Other changes in equipment.**—Other changes except as provided for in these rules or Standards of Good Engineering Practice, prescribed by the Commission, which do not affect the maximum power rating or operating power of the transmitter or the operation or precision of the frequency control equipment may be made at any time without authority of the Commission, but in the next succeeding application for renewal of license such changes which affect the information already on file shall be shown in full.

TECHNICAL OPERATION

§ 3.51 **Operating power; how determined.**—The operating power of each standard broadcast station shall be determined by:

(*a*) Direct measurement of the antenna power in accordance with section 3.54.[55]

(1) Each new standard broadcast station.

(2) Each existing standard broadcast station after June 1, 1941.

(*b*) Indirect measurement by means of the plate input power to the last radio stage on a temporary basis in accordance with sections 3.52 and 3.53.

(1) In the case of existing standard broadcast stations and pending compliance with paragraph (*a*) (2) of this section.

(2) In case of an emergency where the licensed antenna has been damaged or destroyed by storm or other cause beyond the control of the licensee or pending completion of authorized changes[56] in the antenna system.

(*c*) Upon making any change[56] in the antenna system, or in the antenna current measuring instruments, or any other change which may change the characteristics of the antenna, the licensee shall immediately make a new determination of the antenna resistance (see section 3.54) and shall submit application for authority to determine power by the direct method on the basis of the new measurements.

§ 3.52 **Operating power; indirect measurement.**—The operating power determined by indirect measurement from the plate input power of the last radio stage is the product of the plate voltage (E_p), the total plate current of the last radio stage (I_p), and the proper factor (F) given in the following tables: that is

Operating Power $E_p \times I_p \times F$

*A. Factor to be used for stations employing plate modulation in the last radio stage**

	Factor (F) to be used in determining the operating power from the plate input power
Maximum rated carrier power of transmitter:†	
100–1,000 watts	0.70
5,000 and over watts	.80

*B. Factor to be used for stations of all powers using low level modulation**

	Factor (F) to be used in determining the operating power from the plate input power
Class of power amplifier in the last radio stage:	
Class B	0.35
Class BC‡	.65

*C. Factors to be used for stations of all powers employing grid modulation in the last radio stage**

	Factor (F) to be used in determining the operating power from the plate input power
Type of tube in the last radio stage:	
Table C*	0.25
Table D*	.35

* See Power Rating of Vacuum Tubes.

† The maximum rated carrier power must be distinguished from the operating power. (See section 3.15.)

‡ All linear amplifier operation where efficiency approaches that of class C operation.

§ 3.53 **Application of efficiency factors.**—In computing operating power by indirect measurement the above factors shall apply in all cases, and no distinction will be recognized due to the operating power being less than the maximum rated carrier power. (See Plate Efficiency of Last Radio Stage.)

§ 3.54 **Operating power; direct measurement.**—The antenna input power determined by direct measurement is the square of the antenna current times the antenna resistance at the point where the current is measured and at the operating frequency. Direct measurement of the antenna input power will be accepted as the operating power of the station, provided the data on the antenna resistance measurements are submitted under oath giving detailed description of the method used and the data taken. The antenna current shall be measured by an ammeter of accepted accuracy.[57] These data must be submitted to and approved by the Commission before any licensee will be authorized to operate by this method of power determination.[58] The antenna ammeter shall not be changed to one of different type, maximum reading, or accuracy without the authority of the Commission. If any change is made in the antenna system or any change made which may affect the antenna system, the method of determining operating power shall be changed immediately to the indirect method. (See Further Requirements for Direct Measurements of Power.)

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[54] Formal application required. See Standards of Good Engineering Practice for form number.

[55] Program tests on equipment, including a new or different antenna system, will not be authorized unless application for authority to determine power by the direct method has been granted, or is submitted simultaneously with the application for license to cover the construction permit and the application for license will not be granted until such time as the application for direct measurement is approved.

[56] Changes shall not be made except upon making proper request and obtaining approval thereof in accordance with sections 3.45 and 3.58.

§ 3.55 **Modulation.**—(*a*) A licensee of a broadcast station will not be authorized to operate a transmitter unless it is capable of delivering satisfactorily the authorized power with a modulation of at least 85 percent. When the transmitter is operated with 85 percent modulation, not over 10 percent combined audio frequency harmonics shall be generated by the transmitter.

(*b*) All broadcast stations shall have in operation a modulation monitor approved by the Commission.

(*c*) The operating percentage of modulation of all stations shall be maintained as high as possible consistent with good quality of transmission and good broadcast practice and in no case less than 85 percent on peaks of frequent recurrence during any selection which normally is transmitted at the highest level of the program under consideration.

(*d*) The Commission will, from time to time, publish the specifications, requirements for approval, and a list of approved modulation monitors. (See Approved Modulation Monitors and also Requirements for Approval of Modulation Monitors.)

§ 3.56 **Modulation; data required.**—A licensee of a broadcast station claiming a greater percentage of modulation than the fundamental design indicates can be procured shall submit full data showing the antenna input power by direct measurement and complete information, either oscillograms or other acceptable data, to show that a modulation of 85 percent or more, with not over 10 percent combined audio harmonics, can be obtained with the transmitter operated at the maximum authorized power.

§ 3.57 **Operating power; maintenance of.**—The licensee of a broadcast station shall maintain the operating power of the station within the prescribed limits of the licensed power at all times except that in an emergency when, due to causes beyond the control of the licensee, it becomes impossible to operate with the full licensed power, the station may be operated at reduced power for a period of not to exceed 10 days, provided that the Commission and the Engineer in Charge[59] shall be notified in writing immediately after the emergency develops. (See Operating Power Tolerance.)

§ 3.58 **Indicating instruments.**—Each broadcast station shall be equipped with suitable indicating instruments of accepted accuracy to measure the antenna current, direct plate circuit voltage, and the direct plate circuit current of the last radio stage. These indicating instruments shall not be changed or replaced, without authority of the Commission, except by instruments of the same type, maximum scale reading, and accuracy. (See Indicating Instruments Pursuant to section 3.58.)

§ 3.59 **Frequency tolerance.**—The operating frequency of each broadcast station shall be maintained within 50 cycles of the assigned frequency until January 1, 1940, and thereafter the frequency of each new station or each station where a new transmitter is installed shall be maintained within 20 cycles of the assigned frequency, and after January 1, 1942, the frequency of all stations shall be maintained within 20 cycles of the assigned frequency.

§ 3.60 **Frequency monitor.**—The licensee of each standard broadcast station shall have in operation at the transmitter a frequency monitor independent of the frequency control of the transmitter. The frequency monitor shall be approved by the Commission. It shall have a stability and accuracy of at least 5 parts per million. (See Approved Frequency Monitors and also Requirements for Approval of Frequency Monitors.)

General Rules Applicable to Standard Broadcast Stations

§ 3.164 **Station license; posting of.**—The station license and any other instrument of authorization or individual order concerning construction of the equipment or the manner of operation of the station shall be posted in a conspicuous place in the room in which the transmitter is located in such manner that all terms thereof are visible and the license of the station operator shall be posted in the same manner. (See sec. 13.6.)

§ 3.165 **Licensed operator required.**—(*a*) The licensee of each station shall have a licensed operator or operators of the grade specified by the Commission on duty during all periods of actual operation of the transmitter at the place where the transmitting equipment is located. (See sec. 13.7.)

(*b*) The licensed operator on duty and in charge of a standard transmitter may, at the discretion of the licensee, be employed for other duties or for the operation of another radio station or stations in accordance with the class of operator's license which he holds and by the rules and regulations governing such other stations: *Provided, however,* That such duties shall in nowise interfere with the proper operation of the standard broadcast transmitter.

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[57] See Indicating Instruments pursuant to section 3.58.

[58] Formal application required. See Standards of Good Engineering Practice for form number.

[59] See Field Offices of the Commission.

§ 3.170 **Station inspection.**—The licensee of any radio station shall make the station available for inspection by representatives of the Commission at any reasonable hour.

§ 3.181 **Logs.**—The licensee of each standard broadcast station shall maintain program and operating logs and shall require entries to be made as follows:

(*a*) In the program log:

(1) An entry of the time each station identification announcement (call letters and location) is made.

(2) An entry briefly describing each program broadcast, such as "music," "drama," "speech," etc., together with the name or title thereof, and the sponsor's name, with the time of the beginning and ending of the complete program. If a mechanical record is used, the entry shall show the exact nature thereof, such as "record," "transcription," etc., and the time it is announced as a mechanical record. If a speech is made by a political candidate, the name and political affiliations of such speaker shall be entered.

(3) An entry showing that each sponsored program broadcast has been announced as sponsored, paid for, or furnished by the sponsor.

(4) An entry showing, for each program of network origin, the name of the network originating the program.

(*b*) In the operating log:

(1) An entry of the time the station begins to supply power to the antenna, and the time it stops.

(2) An entry of the time the program begins and ends.

(3) An entry of each interruption to the carrier wave, its cause, and duration.

(4) An entry of the following each 30 minutes:

(*i*) Operating constants of last radio stage (total plate current and plate voltage).

(*ii*) Antenna current.

(*iii*) Frequency monitor reading.

(*iv*) Temperature of crystal control chamber if thermometer is used.

(5) Log of experimental operation during experimental period. (If regular operation is maintained during this period, the above logs shall be kept.)

(*i*) A log must be kept of all operation during the experimental period. If the entries required above are not applicable thereto, then the entries shall be made so as to fully describe the operation.

(*c*) Where an antenna or antenna supporting structure(s) is required to be illuminated the licensee shall make entries in the radio station log appropriate to the requirements of section 2.82 (*a*), (*b*), and (*c*) as follows:

(1) The time the tower lights are turned on and off if manually controlled.

(2) The time the daily visual observation of the tower lights was made.

(3) In the event of any observed failure of a tower light.

(*i*) Nature of such failure.

(*ii*) Time the failure was observed.

(*iii*) Time and nature of the adjustments, repairs or replacements made.

(*iv*) Airways Communication Station (C. A. A.) notified of the failure of any tower light not corrected within 30 minutes and the time such notice was given.

(*v*) Time notice was given to the Airways Communication Station (C. A. A.) that the required illumination was resumed.

(4) Upon completion of the periodic inspection required at least once each 3 months.

(*i*) The date of the inspection and the condition of all tower lights and associated tower lighting control devices.

(*ii*) Any adjustments, replacements, or repairs made to insure compliance with the lighting requirements.

§ 3.182 **Logs, retention of.**[60]—Logs of standard broadcast stations shall be retained by the licensee for a period of two years: *Provided, however,* That logs involving communications incident to a disaster or which include communications incident to or involved in an investigation by the Commission and concerning which the licensee has been notified, shall be retained by the licensee until he is specifically authorized in writing by the Commission to destroy them: *Provided, further,* That logs incident to or involved in any claim or complaint of which the licensee has notice shall be retained by the licensee until such claim or complaint has been fully satisfied or until the same has been barred by statute limiting the time for the filing of suits upon such claims.

§ 3.183 **Logs, by whom kept.**—Each log shall be kept by the person or persons competent to do so, having actual knowledge of the facts required, who shall sign the log when starting duty and again when going off duty. The logs shall be made available upon request by an authorized representative of the Commission.

§ 3.184 **Log form.**—The log shall be kept in an orderly manner, in suitable form, and in such detail that the data required for the particular class of station concerned are readily available. Key letters or abbreviations may be used if proper meaning or explanation is contained elsewhere in the log.

§ 3.185 **Correction of logs.**—No log or portion thereof shall be erased, obliterated, or willfully destroyed within the period of retention provided by the rules. Any necessary correction may be made only by the person originating the entry who shall strike out the erroneous portion, initial the correction made, and indicate the date of correction.

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[60] Attention is called to the fact, however, that application forms for licenses and other authorizations require that certain operating program data be supplied. It is suggested that these application forms be kept in mind in connection with maintenance of station program and operating records.

§ 3.186 **Rough logs.**—Rough logs may be transcribed into condensed form, but in such case the original log or memoranda and all portions thereof shall be preserved and made a part of the complete log.

§ 3.187 **Station identification.**—(*a*) A licensee of a standard station shall make station identification announcement (call letters and location) at the beginning and ending of each time of operation and during operation (1) on the hour and (2) either on the half hour or at the quarter hour following the hour and at the quarter hour preceding the next hour: *Provided,*

(*b*) Such identification announcement need not be made on the hour when to make such announcement would interrupt a single consecutive speech, play, religious service, symphony concert, or operatic production of longer duration than 30 minutes. In such cases the identification announcement shall be made at the beginning of the program, at the first interruption of the entertainment continuity, and at the conclusion of the program.

(*c*) Such identification announcement need not be made on the half hour or quarter hours when to make such announcement would interrupt a single consecutive speech, play, religious service, symphony concert, or operatic production. In such cases an identification announcement shall be made at the first interruption of the entertainment continuity and at the conclusion of the program, *Provided,* That an announcement within 5 minutes of the time specified in subdivision (2) of paragraph (*a*) of this section will satisfy the requirements of identification announcements.

(*d*) In the case of variety show programs, baseball game broadcasts, or similar programs of longer duration than 30 minutes, the identification announcement shall be made within 5 minutes of the hour and of the times specified in subdivision (2) of paragraph (*a*) of this section.

(*e*) In the case of all other programs the identification announcement shall be made within 2 minutes of the hour and of the times specified in subdivision (2) of paragraph (*a*) of this section.

(*f*) In making the identification announcement the call letters shall be given only on the channel of the station identified thereby, except as otherwise provided in § 3.287 of the Commission's rules governing FM broadcast stations.

§ 3.188 **Mechanical records.**[61]—Each program broadcast which consists in whole or in part of one or more mechanical reproductions shall be announced in the manner and to the extent set out below.

(*a*) Each such program of longer duration than 30 minutes, consisting in whole or in part of one or more mechanical reproductions, shall be identified by appropriate announcement at the beginning of the program, at each 30-minute interval and at the conclusion of the program: *Provided, however,* That the identifying announcement at each 30-minute interval is not required in case of a mechanical reproduction consisting of a continuous uninterrupted speech, play, religious service, symphony concert, or operatic production of longer than 30 minutes.

(*b*) Each such program of a longer duration than 5 minutes and not in excess of 30 minutes, consisting in whole or in part of one or more mechanical reproductions, shall be identified by an appropriate announcement at the beginning and end of the program.

(*c*) Each such program of 5 minutes or less, consisting in whole or in part of mechanical reproductions, shall be identified by appropriate announcement immediately preceding the use thereof: *Provided, however,* that each such program of one minute or less need not be announced as such.

(*d*) In case a mechanical reproduction is used for background music, sound effects, station identification, program identification (theme music of short duration) or identification of the sponsorship of the program proper, no announcement of the mechanical reproduction is required.

(*e*) The exact form of identifying announcement is not prescribed, but the language shall be clear and in terms commonly used and understood. A licensee shall not attempt affirmatively to create the impression that any program being broadcast by mechanical reproduction consists of live talent.

§ 3.189 **Sponsored programs, announcement of.**—(*a*) In the case of each program for the broadcasting of which money, services, or other valuable consideration is either directly or indirectly paid or promised to, or charged or received by, any radio broadcast station, the station broadcasting such program shall make, or cause to be made, an appropriate announcement that the program is sponsored, paid for, or furnished, either in whole or in part.

(*b*) In the case of any political program or any program involving the discussion of public controversial issues for which any records, transcriptions, talent, scripts, or other material or services of any kind are furnished, either directly or indirectly, to a station as an inducement to the broadcasting of such program, an announcement shall be made both at the beginning and conclusion of such program on which such material or services are used that such records, transcriptions, talent, scripts, or other material or services have been furnished to such station in connection with the broadcasting of such program: *Provided, however,* That only one such announcement need be made in the case of any such program of five minutes' duration or less, which announcement may be made either at the beginning or the conclusion of the program.

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[61] During the annual periods in which daylight saving time will be effective the requirements of this Section are waived with respect to network programs, transcribed and rebroadcast one hour later because of the time differential resulting from the adoption of daylight saving time in some areas, this waiver being applicable whether the off-the-line recording is made by the network itself at one of its key stations or by an individual station, but only when the off-the-line recording is for broadcast one hour later by those stations which operate on standard time. Furthermore, each station which broadcasts network programs one hour later in accordance with this waiver shall make an appropriate announcement at least once each day between the hours of 10 a.m. and 10 p.m., stating that some or all of the network programs which are broadcast by that station are delayed broadcasts by means of transcription, and indicating whether the transcriptions have been made by the network or the individual station. A network organization or individual station taking advantage of this waiver should so advise the Commission.

(*c*) The announcement required by this section shall fully and fairly disclose the true identity of the person or persons by whom or in whose behalf such payment is made or promised, or from whom or in whose behalf such services or other valuable consideration is received, or by whom the material or services referred to in subsection (*b*) hereof are furnished. Where an agent or other person contracts or otherwise makes arrangements with a station on behalf of another, and such fact is known to the station, the announcement shall disclose the identity of the person or persons in whose behalf such agent is acting instead of the name of such agent.

(*d*) In the case of any program, other than a program advertising commercial products or services, which is sponsored, paid for or furnished, either in whole or in part, or for which material or services referred to in subsection (*b*) hereof are furnished, by a corporation, committee, association or other unincorporated group, the announcement required by this section, shall disclose the name of such corporation, committee, association or other unincorporated group. In each such case the station shall require that a list of the chief executive officers or members of the executive committee or of the board of directors of the corporation, committee, association or other unincorporated group shall be made available for public inspection at one of the radio stations carrying the program.

(*e*) In the case of programs advertising commercial products or services, an announcement stating the sponsor's corporate or trade name or the name of the sponsor's product, shall be deemed sufficient for the purposes of this section and only one such announcement need be made at any time during the course of the program.

§ 3.191 **Rebroadcast.**—(*a*) The term "rebroadcast" means reception by radio of the program[62] of a radio station, and the simultaneous or subsequent retransmission of such program by a broadcast station.[63]

(*b*) The licensee of a standard broadcast station may, without further authority of the Commission, rebroadcast the program of a United States standard or high frequency broadcast station, provided the Commission is notified of the call letters of each station rebroadcast and the licensee certifies that express authority has been received from the licensee of the station originating the program.[64]

(*c*) (1) The licensee of a standard broadcast station located within a state or the District of Columbia may, without further authority of the Commission, rebroadcast on a noncommercial basis a noncommercial program of a United States international broadcast station.

(*2*) The licensee of a standard broadcast station located in any territory or insular possession of the United States may, without further authority of the Commission, rebroadcast any program of a United States international broadcast station.

(3) In the case of any rebroadcast under the provisions of this paragraph, the Commission shall be notified of the call letters of each station whose programs are rebroadcast and the licensee shall certify that express authority has been received from the licensee of the station originating the program.

(*d*) No licensee of a standard broadcast station shall rebroadcast the program of any other class of United States radio station without written authority having first been obtained from the Commission upon application accompanied by written consent or certification of consent of the licensee of the station originating the program.[65], [66], [67]

(*e*) In case of a program rebroadcast by several standard broadcast stations, such as a chain rebroadcast, the person legally responsible for distributing the program or the network facilities may obtain the necessary authorization for the entire rebroadcast both from the Commission and from the person or licensee of the station originating the program.

Attention is directed to section 325 (*b*) of the Communications Act of 1934, which reads as follows:

No person shall be permitted to locate, use, or maintain a radio broadcast studio or other place or apparatus from which or whereby sound waves are converted into electrical energy, or mechanical or physical reproduction of sound waves produced, and caused to be transmitted or delivered to a radio station in a foreign country for the purpose of being broadcast from any radio station there, having a power output of sufficient intensity, and/or being so located geographically that its emissions may be received consistently in the United States, without first obtaining a permit from the Commission upon proper application therefor.[68]

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[62] As used in sec. 3.191, program includes any complete program or part thereof, or any signals if other than A-3 emission.

[63] In case a program is transmitted from its point of origin to a broadcast station entirely by telephone facilities in which a section of such transmission is by radio, the broadcasting of this program is not considered a rebroadcast.

[64] The notice and certification of consent shall be given within three (3) days of any single rebroadcast, but in case of the regular practice of rebroadcasting certain programs of a standard or high frequency broadcast station several times during a license period, notice and certification of consent shall be given for the ensuing license period with the application for renewal of license, or at the beginning of such rebroadcast practice if begun during a license period.

[65] The broadcasting of a program relayed by a relay broadcast station (sec. 4.401) is not considered a rebroadcast.

[66] Informal application may be employed.

[67] By Order No. 82, dated and effective June 24, 1941, until further order of the Commission, section 3.191 (*d*) is suspended only insofar as it requires prior written authority of the Commission for the rebroadcasting of programs originated for that express purpose by United States Government radio stations.

Rules Governing FM Broadcast Stations

§ 3.239 **Use of common antenna site.**—No FM broadcast station license or renewal of an FM broadcast station license will be granted to any person who owns, leases, or controls a particular site which is peculiarly suitable for FM broadcasting in a particular area and (*a*) which is not available for use by other FM licensees; and (*b*) no other comparable site is available in the area; and (*c*) where the exclusive use of such site by the applicant or licensee would unduly limit the number of FM stations that can be authorized in a particular area or would unduly restrict competition among FM stations.

§ 3.240 **Multiple ownership.**—(*a*) No person (including all persons under common control)[69] shall, directly or indirectly, own, operate or control more than one FM broadcast station that would serve substantially the same service area as another FM broadcast station owned, operated, or controlled by such person.

(*b*) No person (including all persons under common control) shall, directly or indirectly, own, operate, or control more than one FM broadcast station, except upon a showing (1) that such ownership, operation, or control would foster competition among FM broadcast stations or provide an FM broadcasting service distinct and separate from existing services, and (2) that such ownership, operation, or control would not result in the concentration of control of FM broadcasting facilities in a manner inconsistent with public interest, convenience, or necessity: *Provided, however,* That the Commission will consider the ownership, operation, or control of more than six FM broadcast stations to constitute the concentration of control of FM broadcasting facilities in a manner inconsistent with public interest, convenience, or necessity.

RULES RELATING TO EQUIPMENT

§ 3.251 **Transmitter power.**—The rated power and operating power range of transmitters shall be in accordance with the Standards of Good Engineering Practice concerning FM broadcast stations.

§ 3.252 **Frequency monitor.**—The licensee of each FM broadcast station shall have in operation at the transmitter an approved frequency monitor independent of the frequency control of the transmitter. For detailed requirements thereof see Standards of Good Engineering Practice concerning FM broadcast stations.

§ 3.253 **Modulation monitor.**—The licensee of each FM broadcast station shall have in operation at the transmitter an approved modulation monitor. For detailed requirements thereof see Standards of Good Engineering Practice concerning FM broadcast stations.

§ 3.254 **Required transmitter performance.**—The construction installation, operation, and performance of the FM broadcast transmitting system shall be in accordance with the Standards of Good Engineering Practice Concerning FM Broadcast Stations (sections 8 and 13). The licensee of each FM broadcast station shall make the following equipment performance measurements at least at yearly intervals. (One such set of measurements shall be made during the four-month period preceding the date of filing application for renewal of station license.[70])

(*a*) Audio frequency response from 50 to 15,000 cycles for approximately 25, 50 and 100 percent modulation. Measurements shall be made on at least the following audio frequencies: 50, 100, 400, 1000, 5000, 10,000, and 15,000 cycles. The frequency response measurements should normally be made without deemphasis; however, standard 75 microsecond deemphasis may be employed in the measuring equipment or system provided the accuracy of the deemphasis circuit is sufficient to insure that the measured response is within the prescribed limits.

(*b*) Audio frequency harmonic distortion for 25, 50 and 100 percent modulation for the fundamental frequencies of 50, 100, 400, 1000, and 5000 cycles. Audio frequency harmonics for 100 percent modulation for fundamental frequencies of 10,000 and 15,000 cycles. Measurements shall normally include harmonics to 30,000 cycles. The distortion measurements shall be made employing 75 microsecond deemphasis in the measuring equipment or system.

(*c*) Output noise level (frequency modulation) in the band of 50 to 15,000 cycles in decibels below the audio frequency level representing a frequency swing of 75 kilocycles. The noise measurements shall be made employing 75 microsecond deemphasis in the measuring equipment or system.

(*d*) Output noise level (amplitude modulation) in the band of 50 to 15,000 cycles in decibels below the level representing 100 percent amplitude modulation. The noise measurements shall be made employing 75 microsecond deemphasis in the measuring equipment or system. All measurements shall be made with the equipment adjusted for normal program operation and shall include all circuits between the main studio microphone terminals and the antenna output, including telephone lines, preemphasis circuits and any equalizers employed except for microphones, and without compression if a compression amplifier is installed.

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[68] Formal application required. See Standards of Good Engineering Practice for form number.

[69] The word "control" as used herein is not limited to majority stock ownership, but includes actual working control in whatever manner exercised.

[70] Applications for renewal of licenses expiring prior to February 1, 1950 are not required to indicate that these measurements have been made; applications for renewal of licenses expiring on or after February 1, 1950 shall indicate that the measurements have been made.

The above data, diagrams and appropriate graphs together with a description of measurement procedures and instruments, signed by the engineer making the measurements, shall be kept on file at the transmitter and shall be made available upon request to any duly authorized representative of the Federal Communications Commission.

§ 3.255 **Auxiliary transmitter.**—Upon showing that a need exists for the use of an auxiliary transmitter in addition to the regular transmitter of a broadcast station, a license therefor may be issued provided that:

(*a*) An auxiliary transmitter may be installed either at the same location as the main transmitter or at another location.

(*b*) A licensed operator shall be in control whenever an auxiliary transmitter is placed in operation.

(*c*) The auxiliary transmitter shall be maintained so that it may be put into immediate operation at any time for the following purposes:

(1) The transmission of the regular programs upon the failure of the main transmitter.

(2) The transmission of regular programs during maintenance or modification[71] work on the main transmitter, necessitating discontinuance of its operation for a period not to exceed 5 days.

(3) Upon request by a duly authorized representative of the Commission.

(*d*) The auxiliary transmitter shall be tested at least once each week to determine that it is in proper operating condition and that it is adjusted to the proper frequency, except that in case of operation in accordance with paragraph (*c*) of this section during any week, the test in that week may be omitted provided the operation under paragraph (*c*) is satisfactory. A record shall be kept of the time and result of each test operating under paragraph (*c*). Tests shall be conducted only between midnight and 6 a.m., local standard time.

(*e*) The auxiliary transmitter shall be equipped with satisfactory control equipment which will enable the maintenance of the frequency emitted by the station within the limits prescribed by these regulations.

(*f*) The operating power of an auxiliary transmitter may be less than the authorized power of the main transmitter, but in no event shall it be greater than such power.

§ 3.256 **Alternate main transmitters.**—The licensee of a FM broadcast station may be licensed for alternate main transmitters provided that a technical need[72] for such alternate transmitters is shown and that the following conditions are met:

(*a*) Both transmitters are located at the same place.

(*b*) Both transmitters shall have the same power rating.

(*c*) Both transmitters shall meet the construction, installation, operation, and performance requirements of the Standards of Good Engineering Practice concerning FM broadcast stations.

§ 3.257 **Changes in equipment and antenna system.**—Licensees of FM broadcast stations shall observe the following provisions with regard to changes in equipment and antenna system:

(*a*) No changes in equipment shall be made:

(1) That would result in the emission of signals outside of the authorized channel.

(2) That would result in the external performance of the transmitter being in disagreement with that prescribed in the Standards of Good Engineering Practice concerning FM broadcast stations.

(*b*) Specific authority, upon filing formal application (Form FCC No. 301) therefor, is required for a change in service area or for any of the following changes:

(1) Changes involving an increase or decrease in the power rating of the transmitter.

(2) A replacement of the transmitter as a whole.

(3) Change in the location of the transmitting antenna.

(4) Change in antenna system, including transmission line.

(5) Change in location of main studio, if it is proposed to move the main studio to a different city from that specified in the license.

(6) Change in the power delivered to the antenna.

(7) Change in frequency control and/or modulation system.

(*c*) Specific authority, upon filing informal request therefor, is required for a change in the indicating instruments installed to measure transmitter power output, except by instruments of the same maximum scale reading and accuracy.

(*d*) Other changes, except as above provided for in this section or in Standards of Good Engineering Practice concerning FM broadcast stations prescribed by the Commission may be made at any time without the authority of the Commission, provided that the Commission shall be promptly notified thereof and such changes shall be shown in the next application for renewal of license.

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[71] This includes the equipment changes which may be made without authority as set forth elsewhere in the Rules and Regulations and the Standards of Good Engineering Practice or as authorized by the Commission by letter or by construction permit. Where such operation is required for periods in excess of 5 days, request therefor shall be in accordance with section 1.324.

[72] Such as licensees maintaining 24-hour schedule and needing alternate operation for maintenance, or where developmental work requires alternate operation.

RULES RELATING TO TECHNICAL OPERATION

§ 3.261 **Time of operation.**—All FM broadcast stations will be licensed for unlimited time operation. Until further notice a minimum of 6 hours per day of operation will be required, which shall consist of 3 hours during the period 6 a.m. to 6 p.m., local standard time, and 3 hours during the period 6 p.m. to midnight, local standard time. In an emergency, however, when due to causes beyond the control of a licensee, it becomes impossible to continue operation, the station may cease operation for a period not to exceed 10 days, provided that the Commission and the engineer-in-charge of the radio district in which the station is located shall be notified in writing immediately after the emergency develops.

§ 3.262 **Experimental operation.**—The period between 12 midnight and 6 a.m., local standard time, may be used for experimental purposes in testing and maintaining apparatus by the licensee of any FM broadcast station on its assigned frequency and not in excess of its authorized power, without specific authorization from the Commission.

§ 3.263 **Station inspection.**—The licensee of any FM radio station shall make the station available for inspection by representatives of the Commission at any reasonable hour.

§ 3.264 **Station license, posting of.**—The original of each station license shall be posted in the transmitter room.

§ 3.265 **Operator requirements.**—One or more licensed radio telephone first-class operators shall be on duty at the place where the transmitting apparatus of each station is located and in actual charge thereof whenever it is being operated. The original license (or Form FCC No. 759) of each station operator shall be posted at the place where he is on duty. The licensed operator on duty and in charge of an FM broadcast transmitter may, at the discretion of the licensee, be employed for other duties or for the operation of another station or stations in accordance with the class of operator's license which he holds and by the rules and regulations governing such stations. However, such duties shall in no wise interfere with the operation of the broadcast transmitter.

§ 3.266 **Facsimile broadcasting and multiplex transmission.**—(*a*) FM broadcast stations may transmit simplex facsimile in accordance with transmission standards set forth in the Standards of Good Engineering Practice Concerning FM Broadcast Stations during periods not devoted to FM aural broadcasting. However, such transmissions may not exceed one hour during the period between 7 a.m. and midnight (no limit for the hours between midnight and 7 a.m.) and may not be counted toward the minimum operation required by § 3.261.

(*b*) FM broadcast stations may, upon securing authorization from the Commission, transmit multiplex facsimile and aural broadcast programs for a maximum of three hours between the hours of 7 a.m. and midnight (no limit for the hours between midnight and 7 a.m.) in accordance with transmission standards set forth in the Standards of Good Engineering Practice Concerning FM Broadcast Stations provided that the transmission of facsimile does not impair the quality of the aural program below 10,000 cycles per second, and that a filter or other additional equipment is not required for receivers not equipped to receive facsimile.

§ 3.267 **Operating power: how determined.**—The operating power, and the requirements for maintenance thereof, of each FM broadcast station shall be determined by the methods prescribed in the Standards of Good Engineering Practice concerning FM broadcast stations.

§ 3.268 **Modulation.**—The percentage of modulation of all stations shall be maintained as high as possible consistent with good quality of transmission and good broadcast practice and in no case less than 85 percent nor more than 100 percent on peaks of frequent recurrence during any selection which normally is transmitted at the highest level of the program under consideration.

§ 3.269 **Frequency tolerance.**—The center frequency of each FM broadcast station shall be maintained within 2000 cycles of the assigned center frequency.

§ 3.270 **Inspection of tower lights and associated control equipment.**—The licensee of any FM station which has an antenna or antenna supporting structure(s) required to be illuminated pursuant to the provisions of section 303 (q) of the Communications Act of 1934, as amended:

(*a*) Shall make a visual observation of the tower lights at least once each 24 hours to insure that all such lights are functioning properly as required.

(*b*) Shall report immediately by telephone or telegraph to the nearest Airways Communication Station or office of the Civil Aeronautics Administration any observed failure of the tower lights, not corrected within 30 minutes, regardless of the cause of such failure. Further notification by telephone or telegraph shall be given immediately upon resumption of the required illumination.

(*c*) Shall inspect at intervals of at least once each 3 months all flashing or rotating beacons and automatic lighting control devices to insure that such apparatus is functioning properly as required.

OTHER RULES RELATING TO OPERATION

§ 3.281 **Logs.**—The licensee of each FM broadcast station shall maintain separate program and operating logs for such station: *Provided, however,* If the same licensee operates an FM broadcast station and a standard broadcast station and simultaneously broadcasts the same programs over the facilities of both such stations, one program log may be maintained for both stations for such periods as both stations simultaneously broadcast the same programs. Such licensee shall require entries to be made as follows:

(*a*) In the program log:

(1) An entry of the time each station identification announcement (call letters and location) is made.

(2) An entry briefly describing each program broadcast, such as "music," "drama," "speech," etc., together with the name or title thereof and the sponsor's name, with the time of the beginning and ending of the complete program. If a mechanical record is used, the entry shall show the exact nature thereof, such as "record," transcription," etc., and the time it is announced as a mechanical reproduction. If a speech is made by a political candidate, the name and political affiliations of such speaker shall be entered.

(3) An entry showing that each sponsored program broadcast has been announced as sponsored, paid for, or furnished by the sponsor.

(4) An entry showing, for each program of network origin, the name of the network originating the program.

(*b*) In the operating log:

(1) An entry of the time the station begins to supply power to the antenna, and the time it stops.

(2) An entry of the time the program begins and ends.

(3) An entry of each interruption to the carrier wave, its cause, and duration.

(4) An entry of the following each 30 minutes:

(*i*) Operating constants of last radio stage (total plate current and plate voltage).

(*ii*) R.F. transmission line meter reading.

(*iii*) Frequency monitor reading.

(5) Log of experimental operation during experimental period (if regular operation is maintained during this period, the above logs shall be kept).

(*i*) A log must be kept of all operation during the experimental period. If the entries required above are not applicable thereto, then the entries shall be made so as to fully describe the operation.

(*c*) Where an antenna or antenna supporting structure(s) is required to be illuminated the licensee shall make entries in the radio station log appropriate to the requirements of section 3.270 as follows:

(1) The time the tower lights are turned on and off if manually controlled.

(2) The time the daily visual observation of the tower lights was made.

(3) In the event of any observed failure of a tower light.

(*i*) Nature of such failure.

(*ii*) Time the failure was observed.

(*iii*) Time and nature of the adjustments, repairs or replacements made.

(*iv*) Airways Communication Station (C. A. A.) notified of the failure of any tower light not corrected within 30 minutes and the time such notice was given.

(*v*) Time notice was given to the Airways Communication Station (C. A. A.) that the required illumination was resumed.

(4) Upon completion of the periodic inspection required at least once each 3 months.

(*i*) The date of the inspection and the condition of all tower lights and associated tower lighting control devices.

(*ii*) Any adjustments, replacements or repairs made to insure compliance with the lighting requirements.

§ 3.282 **Logs, retention of.**—Logs of FM broadcast stations shall be retained by the licensee for a period of two years: *Provided, however,* That logs involving communications incident to a disaster or which include communications incident to or involved in an investigation by the Commission and concerning which the licensee has been notified, shall be retained by the licensee until he is specifically authorized in writing by the Commission to destroy them: *Provided, further,* That logs incident to or involved in any claim or complaint of which the licensee has notice shall be retained by the licensee until such claim or complaint has been fully satisfied or until the same has been barred by statute limiting the time for the filing of suits upon such claims.

§ 3.283 **Logs, by whom kept.**—Each log shall be kept by the person or persons competent to do so, having actual knowledge of the facts required, who shall sign the log when starting duty and again when going off duty. The logs shall be made available upon request by an authorized representative of the Commission.

§ 3.284 **Log form.**—The log shall be kept in an orderly manner, in suitable form, and in such detail that the data required for the particular class of station concerned are readily available. Key letters or abbreviations may be used if proper meaning or explanation is contained elsewhere in the log.

§ 3.285 **Correction of logs.**—No log or portion thereof shall be erased, obliterated, or willfully destroyed within the period of retention provided by the rules. Any necessary correction may be made only by the person originating the entry who shall strike out the erroneous portion, initial the correction made, and indicate the date of correction.

§ 3.286 **Rough logs.**—Rough logs may be transcribed into condensed form, but in such case the original log or memoranda and all portions thereof shall be preserved and made a part of the complete log.

§ 3.287 **Station identification.**—(*a*) A licensee of an FM broadcast station shall make separate station identification announcement (call letters and location) for such station: *Provided, however,* That if the same licensee operates an FM broadcast station and a standard broadcast station and simultaneously broadcasts the same programs over the facilities of both such stations, station identification announcements may be made jointly for both stations for periods of such simultaneous operation. If the call letters of the FM station do not clearly reveal that it is an FM station, the joint announcement shall state that one of the stations is an FM station. Station identification announcement shall be made at the beginning and ending of each time of operation and during operation (1) on the hour and (*2*) either on the half hour or at the quarter hour following the hour and at the quarter hour preceding the next hour: *Provided,*

(*b*) Such identification announcement need not be made on the hour when to make such announcement would interrupt a single consecutive speech, play, religious service, symphony concert, or operatic production of longer duration than 30 minutes. In such cases the identification and announcement shall be made at the beginning of the program, at the first interruption of the entertainment continuity, and at the conclusion of the program.

(*c*) Such identification announcement need not be made on the half hour or quarter hours when to make such announcement would interrupt a single consecutive speech, play, religious service, symphony concert, or operatic production. In such cases an identification announcement shall be made at the first interruption of the entertainment continuity and at the conclusion of the program, *Provided,* That an announcement within 5 minutes of the times specified in subdivision (*2*) of paragraph (*a*) of this section will satisfy the requirements of identification announcements.

(*d*) In the case of variety show programs, baseball game programs, or similar programs of longer duration than 30 minutes, the identification announcement shall be made within 5 minutes of the hour and of the times specified in subdivision (*2*) of paragraph (*a*) of this section.

(*e*) In the case of all other programs, the identification announcement shall be made within 2 minutes of the hour and of the times specified in subdivision (*2*) of paragraph (*a*) of this section.

(*f*) In making the identification announcement, the call letters shall be given only on the channel of the station identified thereby except as otherwise provided herein.

§ 3.288 **Mechanical records.**—Each program broadcast which consists in whole or in part of one or more mechanical reproductions shall be announced in the manner and to the extent set out below.

(*a*) Each such program of longer duration than 30 minutes, consisting in whole or in part of one or more mechanical reproductions, shall be identified by appropriate announcement at the beginning of the program, at each 30-minute interval and at the conclusion of the program; *Provided, however,* That the identifying announcement at each 30-minute interval is not required in case of a mechanical reproduction consisting of a continuous uninterrupted speech, play, religious service, symphony concert, or operatic production of longer than 30 minutes.

(*b*) Each such program of a longer duration than 5 minutes and not in excess of 30 minutes, consisting in whole or in part of one or more mechanical reproductions, shall be identified by an appropriate announcement at the beginning and end of the program.

(*c*) Each such program of 5 minutes or less, consisting in whole or in part of mechanical reproductions, shall be identified by appropriate announcement immediately preceding the use thereof: *Provided, however,* That each such program of one minute or less need not be announced as such.

(*d*) In case a mechanical reproduction is used for background music, sound effects, station identification, program identification (theme music of short duration) or identification of the sponsorship of the program proper, no announcement of the mechanical reproduction is required.

(*e*) The exact form of identifying announcement is not prescribed, but the language shall be clear and in terms commonly used and understood. A licensee shall not attempt affirmatively to create the impression that any program being broadcast by mechanical reproduction consists of live talent.

§ 3.289 **Sponsored programs, announcement of.**—(*a*) In the case of each program for the broadcasting of which money, services, or other valuable consideration is either directly or indirectly paid or promised to, or charged or received by, any radio broadcast station, the station broadcasting such program shall make, or cause to be made, an appropriate announcement that the program is sponsored, paid for, or furnished, either in whole or in part.

(*b*) In the case of any political program or any program involving the discussion of public controversial issues for which any records, transcriptions, talent, scripts, or other material or services of any kind are furnished, either directly or indirectly, to a station as an inducement to the broadcasting of such program, an announcement shall be made both at the beginning and conclusion of such program on which such material or services are used that such records, transcriptions, talent, scripts, or other material or services have been furnished to such station in connection with the broadcasting of such program: *Provided, however,* That only one such announcement need be made in the case of any such program of 5 minutes' duration or less, which announcement may be made either at the beginning or conclusion of the program.

(*c*) The announcement required by this section shall fully and fairly disclose the true identity of the person or persons by whom or in whose behalf such payment is made or promised, or from whom or in whose behalf such services or other valuable consideration is received, or by whom the material or services referred to in subsection (*b*) hereof are furnished. Where an agent or other person contracts or otherwise makes arrangements with a station on behalf of another, and such fact is known to the station, the announcement shall disclose the identity of the person or persons in whose behalf such agent is acting instead of the name of such agent.

(*d*) In the case of any program, other than a program advertising commercial products or services, which is sponsored, paid for or furnished, either in whole or in part, or for which material or services referred to in subsection (*b*) hereof are furnished, by a corporation, committee, association or other unincorporated group, the announcement required by this section, shall disclose the name of such corporation, committee, association or other unincorporated group. In each such case the station shall require that a list of the chief executive officers or members of the executive committee or of the board of directors of the corporation, committee, association or other unincorporated group shall be made available for public inspection at one of the radio stations carrying the program.

(*e*) In the case of programs advertising commercial products or services, an announcement stating the sponsor's corporate or trade name or the name of the sponsor's product, shall be deemed sufficient for the purposes of this section and only one such announcement need be made at any time during the course of the program.

Rules Governing Television Broadcast Stations

CLASSIFICATION OF TELEVISION STATIONS AND ALLOCATION OF FREQUENCIES

§ 3.601 **Numerical designation of television channels.**—The channels or frequency bands set forth below are available for television broadcast stations.

Channel No.	*Megacycles*	*Channel No.*	*Megacycles*
		7	174–180
	54–60	8	180–186
	60–66	9	186–192
	66–72	10	192–198
	76–82	11	198–204
	82–88	12	204–210
		13	210–216

RULES RELATING TO EQUIPMENT

§ 3.651 **Transmitter power.**—The rated power and operating power range of transmitters shall be in accordance with the Standards of Good Engineering Practice concerning Television Broadcast Stations.

§ 3.652 **Frequency monitors.**—The licensee of each television broadcast station shall have in operation at the transmitters frequency monitors independent of the frequency control of the transmitters.

§ 3.653 **Modulation monitors.**—The licensee of each television broadcast station shall have in operation at the transmitter a modulation monitor for the aural transmitter. There shall also be sufficient monitoring equipment for the visual signal to determine that the signal complies with the Standards of Good Engineering Practice concerning Television Broadcast Stations.

§ 3.654 **Required transmitter performance.**—The construction, installation, operation, and performance of the television broadcast transmitter system shall be in accordance with the Standards of Good Engineering Practice concerning Television Broadcast Stations.

§ 3.655 **Auxiliary transmitter.**—Upon showing that a need exists for the use of auxiliary transmitters in addition to the regular transmitters of a television station, a license therefor may be issued provided that:

(*a*) Auxiliary transmitters may be installed either at the same location as the main transmitters or at another location.

(*b*) A licensed operator shall be in control whenever auxiliary transmitters are placed in operation.

(*c*) The auxiliary transmitters shall be maintained so that they may be put into immediate operation at any time for the following purposes:

(1) The transmission of the regular programs upon the failure of the main transmitters.

(2) The transmission of regular programs during maintenance or modification [73] work on the main transmitter, necessitating discontinuance of its operation for a period not to exceed five days.

(3) Upon request by a duly authorized representative of the Commission.

(*d*) Each auxiliary transmitter shall be tested at least once each week to determine that it is in proper operating condition and that it is adjusted to the proper frequency, except that in case of operation in accordance with paragraph (*c*) of this section during any week, the test in that week may be omitted provided the operation under paragraph (*c*) is satisfactory. A record shall be kept of the time and result of each test operating under paragraph (*c*).

(*e*) The auxiliary transmitters shall be equipped with satisfactory control equipment which will enable the maintenance of the frequency emitted by the station within the limits prescribed by these regulations.

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[73] This includes the equipment changes which may be made without authority as set forth elsewhere in the Rules and Regulations and the Standards of Good Engineering Practice or as authorized by the Commission by letter or by construction permit. Where such operation is required for periods in excess of 5 days, request therefor shall be in accordance with section 1.324.

(*f*) The operating power of an auxiliary transmitter may be less than the authorized power of the main transmitters, but in no event shall it be greater than such power.

§ 3.656 **Alternate main transmitters.**—The licensee of a television broadcast station may be licensed for alternate main transmitters provided that a technical need for such alternate transmitters is shown and that the following conditions are met:

(*a*) Both transmitters are located at the same place.

(*b*) Both transmitters shall have the same power rating.

(*c*) Both transmitters shall meet the construction, installation, operation, and performance requirements of the Standards of Good Engineering Practice concerning Television Broadcast Stations.

§ 3.657 **Changes in equipment and antenna system.**—Licensees of television broadcast stations shall observe the following provisions with regard to changes in equipment and antenna system:

(*a*) No changes in equipment shall be made:

(1) That would result in the emission of signals outside of the authorized channel.

(2) That would result in the external performance of the transmitter being in disagreement with that prescribed in the Standards of Good Engineering Practice concerning Television Broadcast Stations.

(*b*) Specific authority, upon filing formal application (Form FCC No. 301) therefor, is required for a change in service area or for any of the following changes:

(1) Changes involving an increase or decrease in the power rating of the transmitters.

(2) A replacement of the transmitters as a whole.

(3) Change in the location of the transmitting antenna.

(4) Change in antenna system, including transmission line.

(5) Change in location of main studio, if it is proposed to move the main studio to a different city from that specified in the license.

(6) Change in the power delivered to the antenna:

(7) Change in frequency control and/or modulation system.

(*c*) Specific authority, upon filing *informal* request therefor, is required for a change in the indicating instruments installed to measure transmitter power output, except by instruments of the same maximum scale reading and accuracy.

(*d*) Other changes, except as above provided for in this section or in Standards of Good Engineering Practice concerning Television Broadcast Stations prescribed by the Commission may be made at any time without the authority of the Commission, provided that the Commission shall be promptly notified thereof and such changes shall be shown in the next application for renewal of license.

RULES RELATING TO TECHNICAL OPERATION

§ 3.661 **Time of operation.**—(*a*) All television broadcast stations will be licensed for unlimited time operation. Each such station shall maintain a regular program operating schedule as follows: not less than two hours daily in any five broadcast days per week and not less than a total of twelve hours per week during the first eighteen months of the station's operations; not less than two hours daily in any five broadcast days per week and not less than a total of sixteen hours, twenty hours and twenty-four hours per week for each successive six month period of operation, respectively; and not less than two hours in each of the seven days of the week and not less than a total of twenty-eight hours per week thereafter. "Operation" includes the period during which a station is operated pursuant to special temporary authority or during program tests, as well as during the license period. Time devoted to test patterns, or to aural presentations accompanied by the incidental use of fixed visual images which have no substantial relationship to the subject matter of such aural presentations, shall not be considered in computing periods of program service. If, in the event of an emergency due to causes beyond the control of a licensee, it becomes impossible to continue operation, the Commission and the Engineer in Charge of the radio district in which the station is located shall be notified in writing immediately after the emergency develops and immediately after the emergency ceases and operation is resumed.

(*b*) The aural transmitter of a television broadcast station shall not be operated separately from the visual transmitter except for experimental or test purposes.

(*c*) Persons desiring to enter into a voluntary sharing arrangement of a television channel may file application therefor with the Commission. Copies of the time-sharing agreement should be filed with the application.

§ 3.662 **Experimental operation.**—Television broadcast stations may conduct technical experimentation directed to the improvement of technical phases of operation and for such purposes may utilize a signal other than the standard television signal subject to the following conditions:

(*a*) That the licensee complies with the provisions of section 3.661 with regard to the minimum number of hours of transmission with a standard television signal.

(*b*) That no transmissions are radiated outside of the authorized channel and subject to the condition that no interference is caused to the transmissions of a standard television signal by other television broadcast stations.

(*c*) No charges either direct or indirect shall be made by the licensee of a television broadcast station for the production or transmission of programs when conducting technical experimentation.

§ 3.663 **Station inspection.**—The licensee of any televison broadcast station shall make the station available for inspection by representatives of the Commission at any reasonable hour.

§ 3.664 **Station license, posting of.**—The original of each station license shall be posted in the transmitter room.

§ 3.665 **Operator requirements.**—One or more licensed radio-telephone first class operators shall be on duty at the place where the transmitting apparatus of each station is located and in actual charge thereof whenever it is being operated. The original license (or Form FCC No. 759) of each station operator shall be posted at the place where he is on duty. The licensed operator on duty and in charge of a television broadcast transmitter may, at the discretion of the licensee, be employed for other duties or for the operation of another station or stations in accordance with the class of operator's license which he holds and by the rules and regulations governing such stations. However, such duties shall in no wise interfere with the operation of the broadcast transmitter.

§ 3.666 **Operating power: how determined.**—The operating power, and the requirements for maintenance thereof, of each television broadcast station shall be determined by the methods prescribed in the Standards of Good Engineering Practice concerning Television Broadcast Stations.

§ 3.667 **Modulation.**—The percentage of modulation of the aural transmissions shall be maintained as high as possible consistent with good quality of transmission and good broadcast practice and in no case less than 85 per cent nor more than 100 percent on peaks of frequent recurrence during any selection which normally is transmitted at the highest level of the program under consideration.

§ 3.668 **Frequency Tolerance.**—The operating frequencies of the aural and visual transmitters of a television broadcast station shall be maintained within .002 percent of the assigned frequencies.

§ 3.669 **Inspection of tower lights and associated control equipment.**—The licensee of any television station which has an antenna or antenna supporting structure(s) required to be illuminated pursuant to the provisions of section 303 (q) of the Communications Act of 1934, as amended:

(*a*) Shall make a visual observation of the tower lights at least once each 24 hours to insure that all such lights are functioning properly as required.

(*b*) Shall report immediately by telephone or telegraph to the nearest Airways Communication Station or office of the Civil Aeronautics Administration any observed failure of the tower lights, not corrected within 30 minutes, regardless of the cause of such failure. Further notification by telephone or telegraph shall be given immediately upon resumption of the required illumination.

(*c*) Shall inspect at intervals of at least once each 3 months all flashing or rotating beacons and automatic lighting control devices to insure that such apparatus is functioning properly as required.

OTHER RULES RELATING TO OPERATION

§ 3.681 **Logs.**—The licensee of each television station shall maintain program and operating logs and shall require entires to be made as follows:

(*a*) In the program log:

(1) An entry of the time each station identification announcement (call letters and location) is made.

(2) An entry briefly describing each program broadcast, such as "music," "drama," "speech," etc., together with the name or title thereof and the sponsor's name, with the time of the beginning and ending of the complete program. If a mechanical reproduction, either visual or aural, is used, the entry shall show the exact nature thereof, and the time it is announced as a mechanical reproduction. If a speech is made by a political candidate, the name and political affiliations of such speaker shall be entered.

(3) An entry showing that each sponsored program broadcast has been announced as sponsored, paid for, or furnished by the sponsor.

(4) An entry showing, for each program of network origin, the name of the network originating the program.

(*b*) In the operating log:

(1) An entry of the time the station begins to supply power to the antenna, and the time it stops.

(2) An entry of the time the program begins and ends.

(3) An entry of each interruption to the carrier wave, its cause, and duration.

(4) An entry of the following each 30 minutes:

(i) Operating constants of last radio stage of the aural transmitter (total plate current and plate voltage).

(ii) Transmission line current or voltage of both transmitters.

(iii) Frequency monitor reading.

(5) Log of experimental operation during experimental period (if regular operation is maintained during this period, the above logs shall be kept).

(i) A log must be kept of all operation during the experimental period. If the entries required above are not applicable thereto, then the entries shall be made so as to fully describe the operation.

(*c*) Where an antenna or antenna supporting structure(s) is required to be illuminated, the licensee shall make entries in the radio station log appropriate to the requirements of section 3.669 as follows:

(1) The time the tower lights are turned on and off if manually controlled.

(2) The time the daily visual observation of the tower lights was made.

(3) In the event of any observed failure of a tower light.

(i) Nature of such failure.

(ii) Time the failure was observed.

(iii) Time and nature of the adjustments, repairs or replacements made.

(iv) Airways Communication Station (C. A. A.) notified of the failure of any tower light not corrected within thirty minutes and the time such notice was given.

(v) Time notice was given to the Airways Communication Station (C. A. A.) that the required illumination was resumed.

(4) Upon completion of the periodic inspection required at least once each three months.

(i) The date of the inspection and the condition of all tower lights and associated tower lighting control devices.

(ii) Any adjustments, replacements or repairs made to insure compliance with the lighting requirements.

§ 3.682 **Logs, retention of.**—Logs of television broadcast stations shall be retained by the licensee for a period of two years, *Provided, however,* That logs involving communications incident to a disaster or which include communications incident to or involved in an investigation by the Commission and concerning which the licensee has been notified, shall be retained by the licensee until he is specifically authorized in writing by the Commission to destroy them; *Provided, further,* That logs incident to or involved in any claim or complaint of which the licensee has notice shall be retained by the licensee until such claim or complaint has been fully satisfied or until the same has been barred by statute limiting the time for the filing of suits upon such claims.

§ 3.683 **Logs, by whom kept.**—Each log shall be kept by the person or persons competent to do so, having actual knowledge of the facts required, who shall sign the log when starting duty and again when going off duty. The logs shall be made available upon request by an authorized representative of the Commission.

§ 3.684 **Log form.**—The log shall be kept in an orderly manner, in suitable form, and in such detail that the data required for the particular class of station concerned are readily available. Key letters or abbreviations may be used if proper meaning or explanation is contained elsewhere in the log.

§ 3.685 **Correction of logs.**—No log or portion thereof shall be erased, obliterated, or wilfully destroyed within the period of retention provided by the rules. Any necessary correction may be made only by the person originating the entry who shall strike out the erroneous portion, initial the correction made, and indicate the date of correction.

§ 3.686 **Rough logs.**—Rough logs may be transcribed into condensed form, but in such case, the original log or memoranda and all portions thereof shall be preserved and made a part of the complete log.

§ 3.687 **Station identification.**—(*a*) A licensee of a television broadcast station shall make station identification announcement (call letters and location), at the beginning and ending of each time of operation and during the operation on the hour. The announcement at the beginning and ending of each time of operation shall be by both aural and visual means. Other announcements may be by either aural or visual means.

(*b*) Identification announcements during operation need not be made when to make such announcement would interrupt a single consecutive speech, play, religious service, symphony concert, or any type of production. In such cases the identification announcement shall be made at the first interruption of the entertainment continuity and at the conclusion thereof.

§ 3.688 **Mechanical reproductions.**—(*a*) Each program which consists in whole or in part of one or more mechanical reproductions, either visual or aural, shall be accompanied by an appropriate announcement to that effect either at the beginning or end of such reproduction or at the beginning or end of the program in which such reproduction is used. No such announcement shall be required where a mechanical reproduction is used for background music, sound effects, station identification, program identification (theme music of short duration) or identification of sponsorship of the program proper.

(b) The exact form of identifying announcement is not prescribed, but the language shall be clear and in terms commonly used and understood. The licensee shall not attempt affirmatively to create the impression that any program being broadcast by mechanical reproduction consists of live talent.

CHAPTER 21

INTERNATIONAL TELECOMMUNICATION CONVENTION OF ATLANTIC CITY AND RADIO REGULATIONS, 1947

A new International Radio Conference held in Atlantic City, New Jersey, during 1947 produced the Atlantic City Radio Regulations, 1947, which replace the nine-year-old Cairo Regulations. The Atlantic City Radio Regulations, 1947, coupled to the Atlantic City Convention ratified by the United States Senate, represent the basic and overriding international treaty relative to telecommunications to which our national law and action must conform.

The Atlantic City Radio Regulations provide for significant changes in the operation of both the maritime and aeronautical services. It has been long considered that adequate communication channels should be provided for the joint use of ships and aircraft. Article 33 makes such channels available and provides additional facilities for the promotion of safety, operational communications and the handling of public correspondence between the two services.

Furthermore, a new concept of ship radiotelegraph operation in the high-frequency maritime bands is made possible by a "calling-channelling" plan of operation. This plan provides for a plurality of calling frequencies, specific channelling and harmonic relationship of ship channels throughout the maritime bands except the 22 mc band.

High-frequency Maritime Radiotelegraph Service—Each of the ship radiotelegraph bands are divided into three parts as follows:

(*a*) Passenger ship working
(*b*) Calling
(*c*) Cargo ship working

Each Administration must through its licensing authority assign progressively to each of its cargo ships, in turn, consecutive pairs of working frequencies, each pair equally spaced. Also, each Administration must assign calling frequencies in each calling band in accordance with a system of rotation similar to the foregoing. However, the calling band is to be used jointly by both cargo and passenger vessels. Each ship is to have but one frequency in each calling band.

An aircraft desiring to communicate with coast stations or ships may use the center frequency in any one of the calling bands and then shift to any of the working frequencies for passenger vessels to transmit traffic.

A spacing of 1 kc between calling trequencies in the 4000-kc band was agreed upon which will automatically fix the spacing in the harmonically related calling bands. The center calling frequency in each band is reserved, as far as possible, for aircraft stations to establish communication with stations in the maritime mobile service.

Maritime Mobile Radiotelephone Service—Three important advances having for their purpose the promotion of safety was made in the maritime mobile radiotelephone service. They were as follows:

(*a*) Designation of the frequency 2182 kc as a world-wide calling and distress frequency for the maritime mobile radiotelephone service.

(*b*) Designation of nine series of paired frequencies in the 4000, 8000, 12,000, 16,000 and 22,000 kc bands for assignment to ship and coast stations on the world-wide basis for radiotelephony.

(*c*) Designation of the frequency of 156.8 mc for world-wide use on a simplex basis in the maritime mobile radiotelephone service for calling, safety, intership and harbor control purposes.

Survival Craft Frequency—The Conference allocated the center calling frequency of 8364 kc in the 8000-kc band for use of radio-equipped lifeboats and liferafts. This allocation is in addition to the 500-kc frequency previously used by survival craft. The use of this high frequency has the distinct advantage of being continuously looked over by operators on watch in coast stations while monitoring the 8000-kc band. In addition it permits locating survival craft by high frequency direction-finding nets.

Distress Procedure—Both new and modified regulations were adopted to enhance safety and rescue at sea and in the air. The changes and additions may be summed up as follows:

(1) A ship station which cannot transmit on the international distress frequencies (500 kc and 2182 kc) shall use their normal calling frequency for distress purposes.

(2) When circumstances permit, the transmission of the distress call is separated from the end of the auto-alarm signal by an interval of two minutes. In this case, the alarm signal must be followed immediately by the SOS call sent three times, in order to operate an automatic apparatus which can be actuated by the SOS call since the adoption of the alarm signal and auto-alarm equipment does not prevent an administration from authorizing the use of automatic apparatus which satisfies the condi-

tions of the regulations and can be actuated by the SOS call.

(3) In the radiotelephone service before speaking the distress call "Mayday" attention to its transmission can be preceded by transmitting the SOS call by means of a whistle or any suitable means. The transmission of Mayday spoken three times is followed by the words "this is" and then the identification of the mobile station in distress, repeated three times.

(4) To assist direction finders to obtain bearings on a mobile station in distress, provision is made to transmit two dashes of approximately 10 seconds duration after the transmission of the distress message. Also, immediately before a crash or forced landing of an aircraft or before the total abandonment of a ship or an aircraft, the transmitter must be turned on with the key locked, thus insuring a continuous emission until the power supply fails. This measure enables bearings to be obtained by direction finders on the stricken craft.

(5) The operator of a station in distress may impose silence in his discretion either on all or any station in the area which interferes with the distress traffic. Moreover, the use of the QRT signal must be reserved, as far as possible for the use of the mobile station in distress and for the station controlling distress traffic.

(6) Deletion of certain Cairo regulations so that no unnecessary restrictions will be imposed on communications which do not interfere with distress traffic.

(7) A regulation requiring land stations receiving a distress message to advise, without delay, the authorities participating in operation of the rescue facilities.

(8) Provision made whereby an aircraft may use the urgency signal in the same sense as that used in the maritime mobile service.

(9) A station hearing the safety signal is no longer required to listen until completion of the message following the safety signal but only until it is assumed that the message is of no further interest to itself.

Technical Conditions—The most significant technical requirements imposed by the Atlantic City Regulations as they pertain to the maritime and aeronautical mobile services are as follows:

(*a*) Certain ship stations working on class A1 emission must be able to transmit and receive on at least two working frequencies in addition to one calling frequency in the bands necessary to carry on their services.

(*b*) Changes of frequency for all transmitting and receiving apparatus installed in ship stations for the use of class A1 emissions must be effected within 5 (five) seconds if the frequencies are in the same band, and within 15 (fifteen) seconds if the frequencies are in different bands.

(*c*) The restriction on the energy radiated by receiving apparatus was broadened to include energy radiated in any manner whatsoever instead of that caused by current induced in the antenna and it is specified that the interference produced by such radiation not cause harmful interference to any station rather than to a neighboring station as in Cairo. The Cairo provision was somewhat weakened, although made more specific, by the new requirement that interference must be harmful rather than merely disturbing other stations, as formerly.

(*d*) The recommendation of Cairo that ship stations of the first and second categories be equipped with devices permitting change-over from transmission to reception and vice versa without manual switching was broadened to include all ship radiotelegraph stations and strengthened to require such devices as soon as possible.

In order to take into account the requirements of search and rescue, the following new technical conditions governing the equipment on board survival craft were approved:

(*a*) Compulsory installations must comprise a radiotelegraph equipment capable of transmitting with preferably class A2 emission on 500 kc and, if it provides for the use of frequencies between 4000 and 23,000 kc, on the frequency 8364 kc.

(*b*) If the above equipment includes a receiver, it must be able to receive on the frequency 500 kc, preferably class A2 emission and, where the transmitter employs frequencies between 4000 and 23,000 kc, class A1 and A2 emission throughout the band 8266 to 8745 kc.

General Radiotelegraph Procedure in the Maritime Mobile and Aeronautical Mobile Services—The Atlantic City Conference narrowed the general escape clause of Cairo by confining the discretionary power of the aeronautical service to make up its own procedures to the portions dealing with calls, signals preparatory to traffic, routing of traffic and end of traffic and work. The remaining portions relative to general provisions, preliminary operations, duration and control of work and tests are to be unreservedly applied to the aeronautical mobile service. However, an important exception was made in the case of aircraft stations when communicating with stations of the maritime mobile service. These stations must, under all circumstances, obey all the provisions of this article. This obvious limitation was made necessary in order that the operators of coast and ship stations would not be required to learn another set of procedures to handle the relatively infrequent traffic of aircraft. New regulations were adopted as follows:

(*a*) A new provision was added making the use of the Morse code signals contained in the Telegraph Regulations obligatory in the maritime and aeronautical mobile services but specifying that the use of other signals is not precluded for radiocommunications of a special character;

(*b*) The development of the new high frequency maritime mobile plan required the addition of several new provisions to take care of its specialized requirements. The more important of these provisions, which apply to the bands of frequencies between 4000 and 23,000 kc, are as follows:

(1) In calling, when the conditions of establishing contact are difficult, the call signs may be transmitted more than three times, but not more than eight times except that the call may be repeated at shorter intervals if it is believed no interference will result to communications in progress;

(2) A ship or aircraft station calling a coast station must use a frequency in the calling band especially reserved for this purpose;

(3) When a mobile station calls a coast station, the coast station shall transmit the reply to the call on its normal working frequency in the same band, this frequency being indicated in the List of Coast and Ship Stations;

(*c*) An important principle which the United States has consistently advocated was adopted, which states that the use of frequencies in the bands reserved for calling is forbidden for traffic with the exception of distress traffic;

(*d*) In the case of long radiotelegrams, the handling of traffic by the "break-in" method, which has been the practice for many years, was finally specifically set down as normal procedure in a new provision providing that in cases where both stations are able to change from sending to receiving without manual switching, the sending station may continue to send until all its traffic has been sent or until the receiving station breaks in on the transmission with the service abbreviation "BK." It provides further that before commencing, both stations normally agree on such a method of working by means of the abbreviation "QSK." The former method of sending long radiotelegrams in sections is now to be used only when the "break-in" method cannot be employed;

(*e*) The section dealing with the duration of work was made more general by including all provisions relating to the control of work which necessitated the following changes:

(1) The Cairo provision restricting the work on 333 kc in the aeronautical service to 5 minutes was deleted as not being a subject which the International Telecommunications Union needed to regulate;

(2) The former restriction that, in no case, in the maritime mobile service, must working on 500 kc exceed 5 minutes, was retained, but the remainder of the section dealing with the determination of the duration of the periods of work on other frequencies was deleted and replaced by two general provisions from Cairo Article 20 relative to the control of work. These provisions require that in communication between land stations and mobile stations, the mobile station shall comply with the instructions given by the land station, in all questions relating to the order and time of transmission, to the advice of frequency and of the class of emission, and to the duration and suspension of work, but that this provision does not apply to cases of distress. The second of these provisions states that in communication between mobile stations, the station called controls the working in a similar manner.

(*f*) The section regulating testing was expanded by the inclusion of a provision from Cairo Article 22 requiring that where it is necessary for a mobile station to send signals for testing or adjustment which are liable to interfere with the working of a neighboring coast or aeronautical station, the consent of the station must be obtained before such signals are sent.

Effective Date of the Radio Regulations

1076 § 1. (NEW)[1] These Regulations shall go into force on January 1, 1949, except for the table for the allocation of frequencies covering the bands below 27 500 kc/s[2] and the provisions listed below, which shall go into force upon the effective date of the new International Frequency List, as determined by a special Administrative Radio Conference:

ARTICLE 2

Designation of Emissions

74 § 1. (NEW) Emissions are designated according to their classification and the width of the frequency band occupied by them.

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[1] Wherever a paragraph in the following regulations is labeled NEW or MOD it indicates that the material is different from the Cairo Regulations.

1076.1 (NEW)[2] However, all or any portion of the band 150–2 850 kc/s, which is not subject to consideration by the Provisional Frequency Board, may go into force in Region 2 on or after January 1, 1949, in accordance with special arrangements agreed upon by the interested countries of that Region.

80 § 5. (NEW) The classification of emissions is tabulated below:

Type of Modulation	Type of Transmission	Supplementary Characteristics	Symbol
Amplitude Modulated	Absence of any modulation	—	A0
	Telegraphy without the use of modulating audio frequency (on-off keying)	—	A1
	Telegraphy by the keying of a modulating audio frequency or audio frequencies or by the keying of the modulated emission (special case: an unkeyed modulated emission)	—	A2
	Telephony	Double sideband, full carrier	A3
		Single sideband, reduced carrier	A3a
		Two independent side bands, reduced carrier	A3b
	Facsimile	—	A4
	Television	-	A5
	Composite transmissions and cases not covered by the above		A9
	Composite transmissions	Reduced carrier	A9c
Frequency (or phase) Modulated	Absence of any modulation	—	F0
	Telegraphy without the use of modulating audio frequency (frequency shift keying)	—	F1
	Telegraphy by the keying of a modulating audio frequency or audio frequencies, or by the keying of the modulated emission (special case: an unkeyed emission modulated by audio frequency)	—	F2
	Telephony		F3
	Facsimile	—	F4
	Television	—	F5
	Composite transmissions and cases not covered by the above	-	F9
Pulse Modulated	Absence of any modulation intended to carry information	—	P0
	Telegraphy without the use of modulating audio frequency	—	P1
	Telegraphy by the keying of a modulating audio frequency or audio frequencies, or by the keying of the modulated pulse (special case: an unkeyed modulated pulse)	Audio frequency or audio frequencies modulating the pulse in amplitude	P2d
		Audio frequency or audio frequencies modulating the width of the pulse	P2e

Type of Modulation	Type of Transmission	Supplementary Characteristics	Symbol
		Audio frequency or audio frequencies modulating the phase (or position) of the pulse	P2f
	Telephony	Amplitude modulated	P3d
		Width modulated	P3e
		Phase (or position) modulated	P3f
	Composite transmissions and cases not covered by the above	—	P9

84 § 9. (NEW) The following are examples of the designation of emissions.

Description	Designation
1. Telegraphy 25 words per minute, International Morse Code, carrier modulated by keying only	0.1 A1
2. Telegraphy, 525 c/s tone, 25 words per minute, International Morse Code, carrier and tone keyed or tone only keyed	1.15 A2
3. Amplitude modulated telephony, 3 000 c/s maximum modulation, double sideband, full carrier	6 A3
4. Amplitude modulated telephony, 3 000 c/s maximum modulation, single sideband, reduced carrier	3 A3a
5. Amplitude modulated telephony, 3 000 c/s maximum modulation, two independent sidebands, reduced carrier	6 A3b
6. Vestigial sideband television (one sideband partially suppressed), full carrier (including a frequency modulated sound channel)	6 000 A5, F3
7. Frequency modulated telephony, 3 000 c/s modulation frequency, 20 000 c/s deviation	46 F3
8. Frequency modulated telephony, 15 000 c/s modulation frequency, 75 000 c/s deviation	180 F3
9. One-microsecond pulses, unmodulated, assuming a value of 5 for K	10 000 P0

Section III. Nomenclature of Frequencies

85 § 10. (NEW) Frequencies shall be expressed in kilocycles per second (kc/s) at and below 30 000 kilocycles per second and in megacycles per second (Mc/s) above this frequency.

Frequency Sub-Division		Frequency Range	Metric Sub-Division
VLF	(Very Low Frequency)	Below 30 kc/s	Myriametric Waves
LF	(Low Frequency)	30 to 300 kc/s	Kilometric Waves
MF	(Medium Frequency)	300 to 3 000 kc/s	Hectometric Waves
HF	(High Frequency)	3 000 to 30 000 kc/s	Decametric Waves
VHF	(Very High Frequency)	30 000 kc/s to 300 Mc/s	Metric Waves
UHF	(Ultra High Frequency)	300 to 3 000 Mc/s	Decimetric Waves
SHF	(Super High Frequency)	3 000 to 30 000 Mc/s	Centimetric Waves
EHF	(Extremely High Frequency)	30 000 to 300 000 Mc/s	Millimetric Waves

Section III. Special Cases of Interference

378/379 § 7. (MOD) Except in cases of distress, communications between ship stations or between ship and aircraft stations must not interfere with the work of coast stations. When this work is thus interfered with, the ship or aircraft station which causes it must stop transmitting or change frequencies upon the first request of the coast station concerned.

Section V. Identification of Emissions

383 § 10. (MOD) The transmission of signals without identification is forbidden to all stations.

384 § 11. (NEW) In order that the identification of stations may be as rapid as possible, stations provided with a call sign in accordance with article 19 must, unless the Regulations provide otherwise, transmit this call sign during the course of their transmission as frequently as is practicable and reasonable.

Section II. Allocation of International Series

419 § 4. (MOD) The first character or the first two characters of the call signs given in the following table show the nationality of the stations.

Table of Allocation of Call Signs

Country	Call Signs
United States of America	AAA–ALZ
(Not allocated)	AMA–AOZ
Pakistan	APA–ASZ
India	ATA–AWZ
Commonwealth of Australia	AXA–AXZ
Argentina Republic	AYA–AZZ
China	BAA–BZZ
Chile	CAA–CEZ
Canada	CFA–CKZ
Cuba	CLA–CMZ
Morocco	CNA–CNZ
Cuba	COA–COZ
Bolivia	CPA–CPZ
Portuguese Colonies	CQA–CRZ
Portugal	CSA–CUZ
Uruguay	CVA–CXZ
Canada	CYA–CZZ
Germany	DAA–DMZ
Belgian Congo	DNA–DQZ
Bielorussian Soviet Socialist Republic	DRA–DTZ
Republic of the Philippines	DUA–DZZ
Spain	EAA–EHZ
Ireland	EIA–EJZ
Union of Soviet Socialist Republics	EKA–EKZ
Republic of Liberia	ELA–ELZ
Union of Soviet Socialist Republics	EMA–EOZ
Iran	EPA–EQZ
Union of Soviet Socialist Republics	ERA–ERZ
Estonia	ESA–ESZ
Ethiopia	ETA–ETZ
Union of Soviet Socialist Republics	EUA–EZZ
France and Colonies and Protectorates	FAA–FZZ
Great Britain	GAA–GZZ
Hungary	HAA–HAZ
Switzerland	HBA–HBZ
Ecuador	HCA–HDZ
Switzerland	HEA–HEZ
Poland	HFA–HFZ
Hungary	HGA–HGZ
Republic of Haiti	HHA–HHZ
Dominican Republic	HIA–HIZ
Republic of Colombia	HJA–HKZ
Korea	HLA–HMZ
Iraq	HNA–HNZ
Republic of Panama	HOA–HPZ
Republic of Honduras	HQA–HRZ
Siam	HSA–HSZ
Nicaragua	HTA–HTZ
Republic of El Salvador	HUA–HUZ
Vatican City State	HVA–HVZ
France and Colonies and Protectorates	HWA–HYZ
Kingdom of Saudi Arabia	HZA–HZZ
Italy and Colonies	IAA–IZZ
Japan	JAA–JSZ
Outer Mongolia Peoples Republic	JTA–JVZ
Norway	JWA–JXZ
(Not allocated)	JYA–JZZ
United States of America	KAA–KZZ
Norway	LAA–LNZ
Argentina Republic	LOA–LWZ
Luxemburg	LXA–LXZ
Lithuania	LYA–LYZ
Bulgaria	LZA–LZZ
Great Britain	MAA–MZZ
United States of America	NAA–NZZ
Peru	OAA–OCZ
Republic of Lebanon	ODA–ODZ
Austria	OEA–OEZ
Finland	OFA–OJZ
Czechoslovakia	OKA–OMZ
Belgium and Colonies	ONA–OTZ
Denmark	OUA–OZZ
Netherlands	PAA–PIZ
Curacao	PJA–PJZ
Netherlands Indies	PKA–POZ
Brazil	PPA–PYZ
Surinam	PZA–PZZ
(Service abbreviations)	QAA–QZZ
Union of Soviet Socialist Republics	RAA–RZZ
Sweden	SAA–SMZ
Poland	SNA–SRZ

Country	Call Signs
Egypt	SSA–SUZ
Greece	SVA–SZZ
Turkey	TAA–TCZ
Guatemala	TDA–TDZ
Costa Rica	TEA–TEZ
Iceland	TFA–TFZ
Guatemala	TGA–TGZ
France and Colonies and Protectorates	THA–THZ
Costa Rica	TIA–TIZ
France and Colonies and Protectorates	TJA–TZZ
Union of Soviet Socialist Republics	UAA–UQZ
Ukrainian Soviet Socialist Republic	URA–UTZ
Union of Soviet Socialist Republics	UUA–UZZ
Canada	VAA–VGZ
Commonwealth of Australia	VHA–VNZ
Newfoundland	VOA–VOZ
British Colonies and Protectorates	VPA–VSZ
India	VTA–VWZ
Canada	VXA–VYZ
Commonwealth of Australia	VZA–VZZ
United States of America	WAA–WZZ
Mexico	XAA–XIZ
Canada	XJA–XOZ
Denmark	XPA–XPZ
Chile	XQA–XRZ
China	XSA–XSZ
France and Colonies and Protectorates	XTA–XWZ
Portuguese Colonies	XXA–XXZ
Burma	XYA–XZZ
Afghanistan	YAA–YAZ
Netherlands Indies	YBA–YHZ
Iraq	YIA–YIZ
New Hebrides	YJA–YJZ
Syria	YKA–YKZ
Latvia	YLA–YLZ
Turkey	YMA–YMZ
Nicaragua	YNA–YNZ
Rumania	YOA–YRZ
Republic of El Salvador	YSA–YSZ
Yugoslavia	YTA–YUZ
Venezuela	YVA–YYZ
Yugoslavia	YZA–YZZ
Albania	ZAA–ZAZ
British Colonies and Protectorates	ZBA–ZJZ
New Zealand	ZKA–ZMZ
British Colonies and Protectorates	ZNA–ZOZ
Paraguay	ZPA–ZPZ
British Colonies and Protectorates	ZQA–ZQZ
Union of South Africa	ZRA–ZUZ
Brazil	ZVA–ZZZ
Great Britain	2AA–2ZZ
Principality of Monaco	3AA–3AZ
Canada	3BA–3FZ
Chile	3GA–3GZ
China	3HA–3UZ
France and Colonies and Protectorates	3VA–3VZ
(Not allocated)	3WA–3XZ
Norway	3YA–3YZ
Poland	3ZA–3ZZ
Mexico	4AA–4CZ
Republic of the Philippines	4DA–4IZ
Union of Soviet Socialist Republics	4JA–4LZ
Venezuela	4MA–4MZ
Yugoslavia	4NA–4OZ
British Colonies and Protectorates	4PA–4SZ
Peru	4TA–4TZ
United Nations	4UA–4UZ
Republic of Haiti	4VA–4VZ
Yemen	4WA–4WZ
(Not allocated)	4XA–4ZZ
(Not allocated)	5AA–5ZZ
(Not allocated)	6AA–6ZZ
(Not allocated)	7AA–7ZZ
(Not allocated)	8AA–8ZZ
(Not allocated)	9AA–9ZZ

Inspection of Mobile Stations

493 § 1. (MOD) (1) The governments or appropriate administrations of countries where a mobile station calls may require the production of the license. The operator of the mobile station, or the person responsible for the station, must facilitate this examination. The license must be kept in such a way that it can be produced without delay. As far as possible, the license, or a copy certified by the authority which has issued it, should be permanently exhibited in the station.

494 (2) The inspectors must have in their possession an identity card or badge, issued by the competent authority, which they must show on request of the master or his deputy.

495 (3) When the license cannot be produced or when manifest irregularities are observed, governments or administrations may inspect the radio installations in order to satisfy themselves that these conform to the conditions imposed by these Regulations.

496 (4) In addition, inspectors have the right to require the production of the operators' certificates, but proof of professional knowledge may not be demanded.

498 (2) The government or administration official who has inspected the station must, before leaving it, communicate the result of his inspection to the master or to the person responsible.

ARTICLE 29

General Radiotelegraph Procedure in the Maritime Mobile and Aeronautical Mobile Services

Section I. General Provisions

602 § 1. (MOD) (1) In the maritime mobile and aeronautical mobile services the procedure detailed in this article is obligatory, except in the case of distress calls or of distress traffic, to which the provisions of article 37 are applicable.

603 (MOD) (2) However, in the aeronautical mobile service the procedure contemplated in sections III, IV and V is applicable only in the absence of special arrangements to the contrary made by agreements between the governments concerned.

604 (MOD) (3) Aircraft stations when communicating with stations of the maritime mobile service must use the procedure laid down in this article.

605 § 2. (NEW) The use of the Morse code signals specified in the Telegraph Regulations shall be obligatory in the maritime and aeronautical mobile services. However, for radiocommunications of a special character, the use of other signals is not precluded.

606 § 3. (1) In order to facilitate radiocommunications, stations of the mobile service use the service abbreviations given in appendix 9.

607 (2) In the maritime mobile service, only the service abbreviations given in appendix 9 are to be used.

608 § 4. The provisions of §§ 6, 23, 24 and 25 of this article are applicable to radiotelephone communications in the mobile service.

Section II. Preliminary Operations

609 § 5. In areas where traffic is congested, ship stations must take into account the provisions of **721**.

610 § 6. (1) Before emitting, every station must listen for a period long enough to satisfy itself that it will not cause harmful interference to transmissions in progress within its range; if such interference is likely, the station awaits the first break in the transmission with which it might interfere.

611 (2) If, these precautions having been taken, the emissions of the station happen to interfere with a radio transmission already in progress the following rules are to be applied:

612 *a*) Within the zone of communication of a coast station open to public correspondence or of any aeronautical station, the station whose emission causes the interference must cease sending at the first request of the said coast station or aeronautical station.

613 *b*) In the case where radiocommunication already in progress between mobile stations is interfered with by the emissions of another mobile station, this station must cease sending at the first request of one of the other stations.

614 *c*) The station which requests this cessation must indicate the approximate waiting time imposed on the station whose emission it suspends.

615 Section III. Calls, Reply to Calls and Signals Preparatory to Traffic

616 § 7. *Method of Calling.*

617 (1) The call is made as follows:

—call sign of the station called, not more than three times;
—the word DE;
—call sign of the calling station, not more than three times.

618 (NEW) (2) However, in the bands of frequencies between 4 000 and 23 000 kc/s, when the conditions of establishing contact are difficult, the call signs may be transmitted more than three times, but not more than eight times.

619 § 8. *Frequency to be Used for Calling and for Preparatory Signals.*

620 (1) For making the call and for transmitting preparatory signals, the calling station uses the frequency on which the station called keeps watch.

621 (NEW) (2) A ship station calling a coast station in any of the frequency bands allocated to the maritime mobile service between 4 000 and 23 000 kc/s must use a frequency in the calling band specially reserved for this purpose.

622 § 9. *Indication of the Frequency to be Used for Traffic.*

623 (MOD) (1) The call, as described in **616**, must be followed by the service abbreviation indicating the frequency and, if useful, the class of emission which the calling station proposes to use for the transmission of its traffic.

624 (2) When, as an exception to this rule, the call is not followed by an indication of the frequency to be used for the traffic:

625 *a*) if the calling station is a land station: it indicates that this station proposes to use for traffic its normal working frequency indicated in the list of stations.

626 (MOD) *b*) if the calling station is a mobile station: it indicates that the frequency to be used for traffic is to be chosen by the station called from amongst the frequencies on which the calling station can transmit.

627 § 10. *Indication of the Number of Radiotelegrams or of Transmission in Series.*

628 (1) When the calling station has more than one radiotelegram to transmit to the station called, the above mentioned preparatory signals are followed by the service abbreviation and the figure giving the number of such radiotelegrams.

629 (2) Moreover, when the calling station wishes to send its radiotelegrams in series, it indicates this by adding the service abbreviation for requesting the consent of the station called.

630 § 11. *Form of Reply to Calls.*

The reply to calls is made as follows:
—call sign of the calling station, not more than three times;
—the word DE;
—call sign of the station called.

631 § 12. *Frequency for Reply.*

632 (1) For transmitting the reply to calls and to preparatory signals, the station called uses the frequency on which the calling station must keep watch, unless the calling station has specified a frequency for the reply.

633 (2) As an exception to this rule:

634 (MOD) *a*) When a mobile station calls a coast station on the frequency 143 kc/s, the coast station shall transmit the reply to the call on its normal working frequency in the bands between 90 and 160 kc/s, as indicated in the List of Coast and Ship Stations.

635 (NEW) *b*) When a mobile station calls a coast station in one of the bands authorized for radiotelegraphy between 4 000 and 23 000 kc/s, the coast station shall transmit the reply to the call on its normal working frequency in the same band, this frequency being indicated in the List of Coast and Ship Stations.

636 § 13. *Agreement on the Frequency to be Used for Traffic.*

637 (1) If the station called is in agreement with the calling station, it transmits:

638 *a*) the reply to the call;

639 *b*) the service abbreviation indicating that from that moment onwards it will listen on the frequency announced by the calling station;

640 *c*) if necessary, the indications referred to in **648**;

641 *d*) the letter *K* if the station called is ready to receive the traffic of the calling station;

642 (MOD) *e*) if useful, the service abbreviation and figure indicating the strength and/or readability of the signals received (see appendix 9).

643 (MOD) (2) If the station called is not in agreement with the calling station on the frequency to be employed as the result of the arrangements under **623** and **624**, it transmits:

644 *a*) the reply to the call;

645 (MOD) *b*) the service abbreviation indicating the frequency and, if useful, the class of emission proposed;

646 *c*) if necessary, the indications specified in **648**.

647 (3) When agreement is reached regarding the frequency which the calling station shall use for its traffic, the station called transmits the letter K after the indications contained in its reply.

648 § 14. *Reply to the Request for Transmission by Series.*

The station called, in replying to a calling station which has proposed to transmit its radiotelegrams by series (**629**), indicates, by means of the service abbreviation, its acceptance or refusal. In the former case it specifies, if necessary, the number of radiotelegrams which it is ready to receive in one series.

649 § 15. *Difficulties in Reception.*

650 (MOD) (1) If the station called is prevented from receiving, it replies to the call as indicated in **636**, but it replaces the letter K by the signal ▪ ▬ ▪ ▪ ▪ (wait), followed by a number indicating in minutes the probable duration of the waiting time. If the probable duration exceeds 10 minutes (5 minutes in the case of aircraft stations communicating with stations of the maritime mobile service), the reason for the delay must be given.

651 (2) When a station receives a call without being certain that such a call is intended for it, it must not reply until the call has been repeated and understood. When, on the other hand, a station receives a call which is intended for it, but is uncertain of the call sign of the calling station, it must reply immediately, using the service abbreviation in place of the call sign of this latter station.

Section IV. Forwarding (Routing) of Traffic

652 § 16. *Traffic Frequency.*

653 (1) Every station of the mobile service uses, in principle, for the transmission of its traffic, one of its working frequencies as indicated in the list of stations, for the band in which the call has been made.

654 (MOD) (2) In addition to its normal working frequency, printed in heavy type in the list of stations, every station may use one or more supplementary frequencies in the same band, in conformity with the provisions of article 33.

655 (MOD) (3) The use of frequencies in the bands reserved for calling is forbidden for traffic with the exception of distress traffic (see article 33).

656 (4) If the transmission of a radiotelegram takes place on a frequency and/or class of emission other than that on which the call has been made the transmission of the radiotelegram is preceded by:

—call sign of the station called, not more than three times;
—the word DE;
—call sign of the calling station, not more than three times.

657 (5) If the transmission is made on the same frequency and class of emission as the call, the transmission of the radiotelegram is preceded, if need be by:

—the call sign of the station called;
—the word DE;
—call sign of the calling station.

658 § 17. (NEW) *Numbering in Daily Series.*

As a general rule radiotelegrams of all kinds transmitted by ship stations and radiotelegrams in the service of public correspondence transmitted by aircraft stations are to be numbered in a daily series, number 1 being given to the first radiotelegram sent each day to each separate land station.

659 § 18. *Long Radiotelegrams.*

660 (1) In principle, any radiotelegram containing more than 100 words is regarded as forming a series, or terminates a series already in course of transmission.

661 (NEW) (2) In cases where both stations are able to change from sending to receiving without manual switching, the sending station may continue to send until all its traffic has been sent or until the receiving station breaks in on the transmission with the service abbreviation BK. Before commencing, both stations normally agree on such a method of working by means of the abbreviation QSK.

662 (MOD) (3) If this method cannot be employed, long radiotelegrams, whether in plain language or in code or cypher, are, as a general rule, to be transmitted in sections, each section containing 50 words in the case of plain language and 20 words or groups if code or cypher is used.

663 (4) At the end of each section the signal • • — — • • (?) meaning "Have you received the radiotelegram correctly up to this point?" is transmitted. If the section has been correctly received, the receiving station replies by sending the letter K and the transmission of the radiotelegram is continued.

664 § 19. *Suspension of Traffic.*

When a station of the mobile service transmits on a working frequency of a land station and so causes interference with the transmission of such land station, it must suspend working at the first request of the latter.

Section V. End of Traffic and Work

665 § 20. . *Signal for the End of Transmission.*

666 (1) The transmission of a radiotelegram is terminated by the signal • — • — • (end of transmission), followed by the call sign of the sending station and the letter K.

667 (2) In the case of transmission by series, the end of each radiotelegram is indicated by the signal • — • — • and the end of the series by the call sign of the sending station and the letter K.

668 § 21. *Acknowledgment of Receipt.*

669 (1) The acknowledgment of receipt of a radiotelegram is given by transmitting the letter R, followed by the number of the radiotelegram. Such acknowledgment of receipt is preceded by the following formula:

—call sign of the station which has been sending;
—the word DE;
—call sign of the station which has been receiving.

670 (2) The acknowledgment of receipt of a series of radiotelegrams is given by transmitting the letter R, followed by the number of the last radiotelegram received. Such acknowledgment of receipt is preceded by the above formula.

671 (3) The acknowledgment of receipt is transmitted by the receiving station on the frequency used for the reply to the call (see 631).

672 § 22. *End of Work.*

673 (1) The end of work between two stations is indicated by each of them by means of the signal • • • — • — (end of work), followed by its own call sign.

674 (2) For these signals the sending station continues to use the working frequency and the receiving station the frequency used for the reply to the call.

675 (MOD) (3) The signal • • • — • — (end of work) is also used:

- —when the transmission of radiotelegrams of general information, meteorological information and general safety notices is finished, and
- —when transmission is ended in long distance radiocommunication services with deferred acknowledgment of receipt or without acknowledgment of receipt.

Section VI. Duration and Control of Work

676 § 23. In no case, in the maritime mobile service, must working on 500 kc/s exceed 5 minutes.

677 § 24. (MOD) In communication between land stations and mobile stations, the mobile station shall comply with the instructions given by the land station, in all questions relating to the order and time of transmission, to the choice of frequency and of the class of emission, and to the duration and suspension of work. This provision does not apply to cases of distress.

678 § 25. In communication between mobile stations, except in cases of distress, the station called controls the working in the manner indicated in **677**.

Section VII. Tests

679 § 26. (MOD) Where it is necessary for a mobile station to send signals for testing or adjustment which are liable to interfere with the working of a neighbouring coast or aeronautical station, the consent of the station must be obtained before such signals are sent.

680 § 27. When it is necessary for a station in the mobile service to make test signals, either for the adjustment of a transmitter before making a call or for the adjustment of a receiver, they must not continue for more than 10 seconds and must be composed of a series of VVV followed by the call sign of the station emitting the test signals.

ARTICLE 30

Calls

681 § 1. (MOD) (1) In the aeronautical mobile service the procedure contemplated in this article is applicable, except in the case of special arrangements by agreements between the governments concerned.

682 (NEW) (2) Aircraft stations when communicating with stations of the maritime mobile service must use the procedure laid down in this article.

683 § 2. (1) As a general rule, it rests with the mobile station to establish communication with the land station. The mobile station may call the land station, for this purpose, only after coming within the range of action of the land station.

684 (2) However, a land station having traffic for a mobile station may call this station if it has reason to believe that the mobile station is within range and is keeping watch.

685 § 3. (MOD) (1) In addition, every coast station must, so far as practicable, transmit its calls in the form of "traffic lists" consisting of the call signs in alphabetical order of all mobile stations for which they have traffic on hand. These calls are made at specified times fixed by agreement between the administrations concerned and at intervals of at least two hours and not more than four hours during the working hours of the coast station.

686 (NEW) (2) Coast stations transmit their traffic lists on their normal working frequency.

687 (NEW) (3) They may, however, announce this transmission by the following brief preamble sent on a calling frequency:

—CQ DE . . . (call sign of the calling station)
—QSW followed by the indication of the working frequency on which the traffic list is about to be sent.

In no case may this preamble be repeated.

688 (NEW) (4) The provisions of **687** are obligatory where the frequency 500 kc/s is involved.

689 (NEW) (5) They do not apply to the bands of frequencies between 4 000 and 23 000 kc/s.

690 (6) The hours at which coast stations transmit their traffic lists and the frequencies and classes of emission which they use for this purpose must be stated in the List of Coast and Ship Stations.

691 (7) Mobile stations which hear their call sign during this transmission must reply as soon as they can do so, following as far as possible the order in which they are called.

692 (8) When the traffic cannot be sent immediately, the coast station informs each mobile station concerned of the probable time at which working can begin, and, also if necessary, the frequency and class of emission which will be used for working with it.

693 § 4. When a land station receives calls from several mobile stations at practically the same time, it decides the order in which these stations may transmit their traffic. This decision is based solely on the necessity for allowing each of the calling stations to clear the greatest number of radiotelegrams.

694 § 5. (1) When a station called does not reply to a call sent there times at intervals of two minutes, the calling must cease and must not be renewed until after an interval of fifteen minutes.

695 (2) However, in the case of a communication between a station of the maritime mobile service and an aircraft station, calling may be renewed after an interval of five minutes.

696 (3) Before renewing the call, the calling station must ascertain that the station called is not in communication with another station.

697 (4) The call may be repeated at shorter intervals if there is no reason to believe that it will interfere-with communication in progress.

698 § 6. (MOD) (1) When communication is first established with a land station, any mobile station may, if it deems it advisable in order to avoid confusion, transmit its name in full.

699 (2) When the name and address of the administration or private operating agency controlling a mobile station are not given in the list of stations or are no longer in agreement with the particulars given therein, it is the duty of the mobile station to furnish, as a matter of regular procedure, to the land station to which it transmits traffic, all the necessary information in this respect, using for this purpose the appropriate service abbreviations.

700 § 7. (1) The land station may, by means of the abbreviation PTR ask the mobile station to furnish it with the following information:

701 (MOD) *a*) approximate distance in nautical miles and bearing in relation to the land station, position in latitude and longitude (Greenwich), course and speed;

702 *b*) next place of call.

703 (MOD) (2) The information referred to in **700** is furnished on the authority of the master or the person responsible for the vehicle carrying the mobile station.

ARTICLE 31

General Call "To All Stations"

704 § 1. Two types of calling signal "To all stations" are recognized:

705 *a)* Call CQ followed by the letter K (see **707** and **708**);

706 *b)* Call CQ not followed by the letter K (see **709**).

707 § 2. Stations desiring to enter into communication with stations of the mobile service, without, however, knowing the names of any such stations within their range of action, may use the enquiry signal CQ, in place of the call sign of the station called in the calling formula, the call being followed by the letter K (general call to all stations in the mobile service with request for reply).

708 § 3. (MOD) In the maritime mobile service, in regions where traffic is congested, the use of the call CQ followed by the letter K is forbidden. As an exception it may be used with signals denoting urgency.

709 § 4. The call CQ not followed by the letter K (general call to all stations without request for reply) is used before the transmission of information of any kind intended to be read or used by anyone who can intercept it.

ARTICLE 32

Call to Several Stations Without Request for Reply

710 The call CP followed by two or more call signs or by a code word (call to certain receiving stations without request for reply) is used only for the transmission of information of any nature intended to be read or used by the persons authorized.

ARTICLE 33

Use of Frequencies for Radiotelegraphy in the Maritime Mobile and Aeronautical Mobile Services

Section I. Restrictions

711 § 1. (1) The use of class B emissions is forbidden in all stations.[3]

712 (2) However, it is permitted for emergency (reserve) installations of ship stations and for lifeboat, liferaft and survival craft equipments.

(MOD) Section II. Bands between 405 and 535 kc/s

713 § 2. (MOD) The provisions of this section are applicable to aircraft stations when communicating with stations of the maritime mobile service.

A. Distress.

714 § 3. (MOD) (1) The frequency 500 kc/s is the international distress frequency; it is used for this purpose by ship or aircraft stations using frequencies in the band 405 to 535 kc/s when requesting assistance from the maritime services. It is used for the distress call and distress traffic, and for urgency and safety signals and messages.

715 (2) In addition it may be used only:
a) for call and reply (see **720** and **722**);

716 (MOD) *b)* by coast stations to announce the transmission of their traffic lists under the conditions provided for in **688**.

711.1 [3] Exceptionally, the ship stations of Australia may, when operating within proximity of the coast of that country, continue to use temporarily their existing damped wave equipment on the frequencies 425 and 500 kc/s.

717 (3) As an exception, however, the frequency 500 kc/s may be used for traffic, outside regions of heavy traffic, under the conditions provided for in **727**, **728** and **729**.

718 (MOD) (4) Apart from the transmissions authorized on 500 kc/s, and taking account of **721**, all transmissions on the frequencies included between 490 and 510 kc/s are forbidden.

719 (NEW) (5) In order to facilitate the reception of distress calls, all stations working on the frequency 500 kc/s must reduce to the minimum their transmissions on this frequency.

B. Call and Reply.

720 § 4. (MOD) (1) The general calling frequency, which must be used by any ship station or coast station engaged in radiotelegraphy in the authorized bands between 405 and 535 kc/s, and by aircraft desiring to enter into communication with a station of the maritime mobile service using frequencies in this band, is the frequency 500 kc/s.

721 (2) However, in order to reduce interference in regions of heavy traffic, administrations reserve the right to consider the requirements of **720** as satisfied when the calling frequencies assigned to coast stations open to public correspondence are not separated by more than 5 kilocycles from the general calling frequency 500 kc/s.

722 § 5. (1) The frequency for replying to a call sent on the general calling frequency (see **720**) is the frequency 500 kc/s, the same as that of the call.

723 (NEW) (2) However, in regions of heavy traffic, ship stations should, as far as possible, ask coast stations to answer by means of their normal working frequency (see **632**).

C. Traffic.

724 § 6. (MOD) (1) Coast stations working in the authorized bands between 405 and 535 kc/s must be able to use at least one frequency in addition to 500 kc/s. One of these additional frequencies which is printed in heavy type in the List of Coast and Ship Stations is the normal working frequency of the station.

725 (MOD) (2) In addition to their normal working frequency coast stations may use, in the authorized bands, additional frequencies which are shown in ordinary type in the List of Coast and Ship Stations. The band of frequencies 405 to 415 kc/s, however, is assigned to radio direction-finding; it may not be used by the mobile service except on the conditions fixed by chapter III.

726 (NEW) (3) The working frequencies of coast stations must be chosen so as to avoid interference with neighboring stations.

727 § 7. (MOD) As an exception to the provisions of **714**, and on condition that signals of distress, urgency and safety, and calls and replies are not interfered with, the frequency 500 kc/s may also be used:

728 (MOD) *a*) for the transmission of a single short radiotelegram exclusively by ship stations of Australia, India, New Zealand and Pakistan when operating in proximity to the coast of their respective countries;[4]

729 *b*) outside areas of heavy traffic for direction-finding but with discretion.

730 § 8. (MOD) (1) Ship stations employing class A1 or A2 emissions in the authorized bands between 405 and 535 kc/s must use, wherever practicable, working frequencies chosen from amongst the following: 425, 454, 468 and 480 kc/s.
(NEW) In addition, the frequency 512 kc/s may be used in regions 1 and 3 and the frequency 448 kc/s in region 2.

728.1 [4] Certain coast stations of India and Pakistan are also permitted temporarily to transmit a single short radiotelegram on 500 kc/s.

731 (MOD) (2) No coast station is authorized to transmit on these working frequencies allocated for the use of ship stations on a world wide basis or on the working frequency allocated for the use of ship stations in the region in which the coast station is situated.

732 (NEW) (3) In regions 1 and 3 the frequency 512 kc/s may also be used by ship and coast stations as a supplementary calling frequency when 500 kc/s is being used for distress purposes.

D. Watch.

733 § 9. (MOD) (1) In order to increase the safety of life at sea and over the sea, all stations of the maritime mobile service normally keeping watch on frequencies in the authorized bands between 405 and 535 kc/s must, during their hours of service, take the necessary measures to ensure watch on the international distress frequency 500 kc/s for three minutes twice an hour beginning at x h 15 and x h 45, Greenwich mean time (G.M.T.).

734 (2) During the periods mentioned above, except for the emissions provided for in article 37 (see **934** to **949**):

735 (MOD) *a*) transmissions must cease within the bands 485 to 515 kc/s;

736 *b*) outside this band, transmissions of stations of the mobile service may continue; stations of the maritime mobile service may listen to these transmissions on the express conditions that they first ensure watch on the distress frequency as provided by **733**.

737 § 10. (MOD) (1) Stations of the maritime mobile service open to public correspondence and using frequencies in the authorized bands between 405 and 535 kc/s must, during their hours of service, remain on watch on the calling frequency 500 kc/s. This watch is only obligatory for class A2 emissions.

738 (MOD) (2) These stations, while observing the provisions of **733**, are authorized relinquish this watch only when they are engaged in communication on other frequencies.

739 (NEW) (3) When they are engaged in such communications:
—Ship stations may maintain this watch by means of an operator, a loudspeaker, or by some other appropriate means such as an automatic alarm receiver.
—Coast stations may maintain this watch either by means of an operator or by loudspeaker; in the latter case an indication may be inserted in the List of Coast and Ship Stations.

Section III. Bands between 90 and 160 kc/s

A. Call and Reply.

740 § 11. (MOD) (1) The frequency 143 kc/s (class A1 only) is the international calling frequency used in the maritime mobile service in the bands 90 to 160 kc/s.

741 (2) Apart from the frequency 143 kc/s, the use of any frequency between 140 and 146 kc/s is forbidden.

742 § 12. (MOD) The frequency for replying to a call sent on the frequency 143 kc/s is:
—for a ship station, the frequency 143 kc/s;
—for a coast station, its normal working frequency.

B. Traffic.

743 § 13. (MOD) (1) The following rules must be observed by stations of the maritime mobile service using class A1 emissions in the bands 90 to 160 kc/s:

744 (MOD) (2) *a*) Every coast station must keep watch on the frequency 143 kc/s unless the List of Coast and Ship Stations provides otherwise.

745 *b*) The coast station transmits its traffic on the working frequency or frequencies specially assigned to it.

746 (NEW) (3) *a*) When a ship station desires to establish communication with another station of the maritime mobile service, it must use the frequency 143 kc/s, unless the List of Coast and Ship Stations provides otherwise.

747 (MOD) *b*) This frequency must be used exclusively:
—for individual calls and replies to such calls;
—for the transmission of signals preparatory to traffic.

748 (MOD) (4) A ship station after establishing communication with another station of the maritime mobile service on the general calling frequency 143 kc/s must, so far as practicable, transmit its traffic on some other frequency in the authorized bands, provided that it does not disturb the work in progress at another station.

749 § 14. (MOD) (1) As a general rule, any ship station working in the bands 110 to 160 kc/s when it is not engaged in communication with other stations of the maritime mobile service must, during its hours of service, keep watch every hour on the frequency 143 kc/s for five minutes beginning at x h 35, Greenwich mean time (G.M.T.).

750 (2) The frequency 143 kc/s may be used for individual calls and will preferably be used for this purpose during the period indicated in **749**.

Section IV. Bands included between 1 605 and 2 850 kc/s

751 § 15. (NEW) Except where regional agreements specify otherwise, the frequencies assigned to ship stations for radiotelegraph communication in the bands between 1 605 and 2 850 kc/s must, as far as possible, be harmonically related (subharmonics) to the frequencies assigned to ship stations in the 4 000 kc/s radiotelegraph band (see section V).

Section V. Bands included between 4 000 and 23 000 kc/s

A. General.

752 § 16. (MOD) (1) Mobile radiotelegraph stations equipped to operate in the frequency bands of the maritime mobile service between 4 000 and 23 000 kc/s must employ only class A1 emission. However, for radiocommunication of a special character, and for survival craft stations (see **600**), the use of other classes of emission is not precluded.

753 (NEW) (2) The rules of procedure fixed in article 29 are applicable to stations of the maritime mobile service using frequencies in the bands between 4 000 and 23 000 kc/s.

754 (NEW) (3) Stations of the maritime mobile service open to public correspondence and using frequencies in the bands 405 to 535 kc/s in addition to frequencies in the band 4 000 to 23 000 kc/s are required to observe the provisions of **737**.

755 § 17. (NEW) (1) Beginning at the low frequency end, each of the radiotelegraph bands reserved for the use of ship stations is divided into three bands as follows:

756 (NEW) *a*) A band of working frequencies for the use of passenger ships.[5]

757 (NEW) *b*) A band of calling frequencies for the use of all ship and aircraft stations entering into communication with stations of the maritime mobile service.

758 (NEW) *c*) A band of working frequencies for the use of cargo ships.

759 (NEW) (2) For the purposes of this section:
—a passenger ship is a vessel defined as such by the Convention for the Safety of Life at Sea.
—a cargo ship is any ship that is not a passenger ship as defined above.

760 (NEW) (3) The arrangement of the frequencies in the ship radiotelegraph bands is illustrated graphically in appendix 10.

756.1 [5] Exceptionally, whaling factory vessels handling a large volume of traffic may use frequencies in this band from October to March of each year.

761 § 18. (NEW) For the exchange of radiotelegraph communications with stations of the maritime mobile service, aircraft stations may utilize the frequencies allocated to that service for radiotelegraphy between 4 000 and 23 000 kc/s. When using these frequencies, aircraft stations must comply with the provisions of this Section.

B. Call and Reply.

762 § 19. (NEW) (1) In order to establish communication with a station in the maritime mobile service, every ship and aircraft station must use a calling frequency in the bands listed in **775**.

763 (NEW) (2) Frequencies in the calling bands are assigned to each mobile station in accordance with the provisions of **776** to **780** inclusive.

764 § 20. (NEW) In order to reduce interference mobile stations must, within the means at their disposal, endeavour to select for calling the band with the most favourable propagational characteristics for effecting reliable communication. In the absence of more precise data, a mobile station must, before making a call, listen for the signals of the station with which it desires to communicate. The strength and readability of such signals is a useful guide to propagational conditions and should indicate which is the preferable band for calling.

765 § 21. (NEW) (1) The calling frequency to be used by a coast station, in each of the bands for which it is equipped, is its normal working frequency as shown in heavy type in the List of Coast and Ship Stations (see **774**).

766 (NEW) (2) A coast station, as a general rule, transmits its calls at specified times in the form of traffic lists on the frequency or frequencies indicated in the List of Coast and Ship Stations (see **685** and **686**).

767 § 22. (NEW) Unless the calling station specifies otherwise, the frequency for reply to a call made in any maritime mobile band is as follows:

768 (NEW) *a)* for a mobile station, its assigned calling frequency in the same band as that used by the calling station;

769 (NEW) *b)* for a coast station, its normal working frequency in the same band as that used by the calling station.

770 § 23. (NEW) When notifying the transmitting frequencies of a coast station, administrations also indicate on which of the ship calling bands the station keeps watch and, as far as possible, the approximate hours of watch keeping in Greenwich mean time (G.M.T.). This information shall be published in the List of Coast and Ship Stations.

C. Traffic.

771 § 24. (NEW) (1) A mobile station, after establishing communication on a calling frequency (see **762**), changes to a working frequency for the transmission of traffic. No traffic shall be transmitted on any frequency in the calling bands.

772 (NEW) (2) Working frequencies shall be assigned to mobile stations in accordance with the provisions of **781** to **797** inclusive.

773 § 25. (NEW) (1) A coast station shall transmit its traffic on its normal working frequency or on other working frequencies assigned to it.

774 (NEW) (2) Working frequencies of coast stations using the bands between 4 000 and 23 000 kc/s are included within the following limits:

4 238 to 4 368 kc/s
6 357 to 6 525 kc/s
8 476 to 8 745 kc/s
12 714 to 13 130 kc/s
16 952 to 17 290 kc/s
22 400 to 22 650 kc/s

D. Assignment of frequencies to mobile stations.[6]

1. Calling frequencies of Ship Stations

775 § 26. (NEW) (1) The calling frequencies assigned to ship stations are included within the following bands:

4 177	to	4 187	kc/s
6 265.5	to	6 280.5	kc/s
8 354	to	8 374	kc/s
12 351	to	12 561	kc/s
16 708	to	16 748	kc/s
22 220	to	22 270	kc/s

776 (NEW) (2) In the 4 000 kc/s maritime mobile service band, the calling frequencies must be uniformly distributed within the calling band. They are preferably spaced 1 kc/s apart. The extreme frequencies assignable are 4 178 and 4 186 kc/s as indicated in appendix 10.

777 (NEW) (3) In each of the other maritime mobile service bands between 4 000 and 18 000 kc/s, the calling frequencies must be in harmonic relationship with those in the 4 000 kc/s calling band. In the 22 000 kc/s calling band, the preferable spacing of calling frequencies is 5 kc/s.

778 § 27. (NEW) The administration to which a ship station is subject shall assign to it a series of calling frequencies including one frequency in each of the bands in which the station is equipped to transmit. In the bands between 4 000 and 18 000 kc/s, the frequencies assigned to each ship station shall be in harmonic relationship. Each administration must take the necessary steps to assign such harmonic series of calling frequencies to ships in accordance with an orderly system of rotation so as to distribute these frequencies uniformly throughout the calling bands as outlined in **776**. The same system of uniform distribution shall be applied in the assignment of calling frequencies in the 22 000 kc/s calling band.

779 § 28. (NEW) (1) The centre calling frequency in each of the calling bands indicated in **775** shall be reserved as far as possible for the use of aircraft desiring to communicate with stations of the maritime mobile service. These frequencies are the following: 4 182; 6 273; 8 364; 12 546; 16 728 and 22 245 kc/s.

780 (NEW) (2) The frequency 8 364 kc/s must be used by lifeboats, liferafts and other survival craft, if they are equipped to transmit on frequencies between 4 000 and 23 000 kc/s, and if they desire to establish with stations of the maritime mobile service communications relating to search and rescue operations see (**600**).

2. Working frequencies of mobile stations

a) General.

781 § 29. (NEW) (1) The working frequencies for passenger ships are so spaced as to provide clear channels. In the 4 000 kc/s band, the two channels adjacent to the calling band are 5 kc/s wide and the remainder are 2.5 kc/s wide, the extreme frequencies assignable being 4 135 and 4 175 kc/s as indicated in appendix 10.

782 (NEW) (2) In the 4 000 kc/s band, the working frequencies of cargo ships are spaced 0.5 kc/s apart, the extreme frequencies assignable being 4 188 and 4 236.5 kc/s as indicated in appendix 10.

783 (NEW) (3) The working frequencies assigned to each ship station in the 6 000, 8 000, 12 000 and 16 000 kc/s bands must be harmonically related to those assigned in the 4 000 kc/s band.

774.1 (NEW) [6] Although this section requires the assignment of specific frequencies to all ship stations operating in the bands between 4 000 and 23 000 kc/s, it is recommended that in the case of certain older types of transmitters now in use, the reference point for measuring frequency deviations shall be that frequency on which the emission begins. This recommendation applies only until such transmitters have been replaced or modified so as to meet the tolerance requirements specified in column 3 of appendix 3.

784 (NEW) (4) In the case of the 22 000 kc/s band, which is not in harmonic relationship with the other bands, the frequencies are spaced as follows and indicated in appendix 10:

785 (NEW) *a*) in the passenger ship band the two channels adjacent to the calling band are 20 kc/s wide and the remaining channels are 10 kc/s wide, the extreme frequencies assignable being 22 075 and 22 215 kc/s;

786 (NEW) *b*) in the cargo ship band the working frequencies are spaced 2.5 kc/s apart, the extreme frequencies assignable being 22 272.5 and 22 395 kc/s.

787 § 30. (NEW) All mobile stations licensed to operate in the maritime mobile bands between 4 000 and 23 000 kc/s must be assigned, as soon as possible, working frequencies in the bands for which they are equipped in accordance with **788** to **797** inclusive.

b) *Working frequencies of passenger ships.*

788 § 31. (NEW) The working frequencies assigned to passenger ships are included within the following bands:

4 133 to 4 177 kc/s
6 200 to 6 265.5 kc/s
8 265 to 8 354 kc/s
12 400 to 12 531 kc/s
16 530 to 16 708 kc/s
22 070 to 22 220 kc/s

789 § 32. (NEW) (1) Each administration shall assign to each of the passenger ships under its jurisdiction two or more series of working frequencies designated in appendix 10 for vessels of this class. The total number of series assigned to each ship should be determined by the anticipated traffic volume.

790 (NEW) (2) When passenger ships are assigned less than the total number of working frequencies in a band, the administration concerned shall assign working frequencies to such ships in accordance with an orderly system of rotation which will ensure approximately the same number of assignments on any one frequency.

791 (NEW) (3) In each band, the two frequencies nearest to the calling frequencies, indicated by solid lines in appendix 10 are assigned to passenger ship stations the emissions of which do not already comply with the frequency tolerance of 0.02% specified in the 3rd column of appendix 3.[7] These frequencies must also be used by mobile stations employing special types of wide band transmission which cannot be contained within the channels indicated by dashed lines in appendix 10.

792 § 33. (NEW) For the exclusive purpose of communicating with stations of the maritime mobile service an aircraft station may be assigned one or more series of working frequencies in the passenger ship bands. These frequencies shall be assigned in accordance with the same system of uniform distribution provided for passenger ships.

c) *Working frequencies of cargo ships.*

793 § 34. (NEW) Working frequencies assigned to cargo ships shall be included within the following bands:

4 187 to 4 238 kc/s
6 280.5 to 6 357 kc/s
8 374 to 8 476 kc/s
12 561 to 12 714 kc/s
16 748 to 16 952 kc/s
22 270 to 22 400 kc/s

791.1 (NEW) [7] It is anticipated that the number of these transmitters on passenger ships will decrease progressively before the effective date of the application of the tolerances specified in column 3 of appendix 3. These channels will be thus gradually cleared for the use of special types of wide-band transmission.

794 § 35. (NEW) (1) In each of the cargo ship bands the assignable frequencies are divided into two equal groups A and B, group A comprising the frequencies in the lower half of the band and group B the frequencies in the upper half (see appendix 10).

795 (NEW) (2) Each administration shall assign to each of its cargo ships two series of working frequencies, one in group A and the other in group B. In each band these two working frequencies are separated from each other by half the width of the assignable band.

796 (NEW) (3) For example, if the frequency assigned to a ship station is the lowest frequency assignable in group A, the other must be the lowest frequency assignable in group B. If one of the frequencies assigned is the second frequency from the low frequency end of group A, then the other frequency assigned must be the second frequency from the low frequency end of group B, etc.

797 (NEW) (4) Each administration shall assign successively one such pair of frequencies to each of its ship stations, commencing at either end of the band. When all available working frequencies in a band have been assigned in this manner the process shall be repeated as often as is necessary to satisfy all its requirements and to insure a uniform distribution of assignments throughout the band.

d) *Abbreviations for the designation of working frequencies.*

798 § 36. (NEW) The following system of abbreviations may be used to designate working frequencies:

799 (NEW) *a*) In the case of a working frequency included between 4 000 and 23 000 kc/s, transmit the last three figures of the frequency excluding fractions of a kilocycle;

800 (NEW) *b*) When the calling station does not know the working frequencies of a cargo ship station, it may request the ship station to reply on its working frequency in group A or on its working frequency in group B by transmitting QSW A or QSW B as the case may be.

Section VI. Aeronautical Mobile Service

801 § 37. (NEW) Agreements between the interested governments may fix frequencies for call and reply in the aeronautical mobile service. These frequencies, as well as the conditions governing their use, are listed in the service documents published by the Secretary General of the Union.

802 § 38. (NEW) For the use of the frequency 500 kc/s for calling and distress purposes, see **711** to **723**.

803 § 39. (MOD) In regions 1 and 3, the frequency 333 kc/s is the general calling frequency for aircraft stations operating in the bands 325–405 kc/s.

Section IV. Ship Stations

842 § 6. (MOD) (1) For the international service of public correspondence, ship radiotelegraph stations are divided into three categories:

843 —Stations of the first category: these stations maintain a continuous service;

844 —Stations of the second category: these stations maintain a service of limited duration as indicated in **847** and **848**;

845 (MOD) —Stations of the third category: these stations maintain a service the duration of which is either shorter than that of stations of the second category, or is not fixed by these Regulations.

846 (NEW) (2) Each government shall itself determine the rules under which ship radiotelegraph stations subject to it are to be placed in one or the other of the above three categories.

847 § 7. (1) Ship stations of the second category must provide service at least during the hours fixed by appendix 13. These hours are mentioned in the license.

848 (2) In case of short voyages, they provide service during the hours fixed by the administration to which they are subject.

849 § 8. When practicable, the hours of service of ship stations of the third category may be mentioned in the List of Stations.

850 § 9. As a general rule, when a coast station has traffic on hand for a ship station of the third category not having fixed hours of service and assumed to be within range of the coast station, the latter calls the ship station during the first half-hour of the first and third periods of service for ships of the second category performing an eight-hour service, in accordance with the provisions of appendix 13.

851 § 10. (NEW) For the international service of public correspondence, ship stations equipped exclusively for the use of radiotelephony constitute a single category. These stations carry on a service the duration of which is not determined by these Regulations.

852 § 11. (1) Ship stations whose service is not continuous may not close before:

853 (MOD) *a*) finishing all operations resulting from a distress call, urgency or safety signal;

854 (MOD) *b*) exchanging so far as practicable all traffic originating in or destined for coast stations situated within their range and mobile stations which, being within their range, have indicated their presence before the actual cessation of work.

855 (MOD) (2) Any ship station not having fixed working hours must inform the coast stations, with which it is in communication, of the time of closing and the time of reopening its service.

856 § 12. (1) *a*) Any mobile station arriving in port, and whose service is therefore about to close, must so notify the nearest coast station and, if necessary, the other coast stations with which it generally communicates.

857 (MOD) *b*) It must not close until after the disposal of traffic on hand, unless the regulations in force in the country where it is calling do not permit this.

858 (MOD) (2) Upon departure from port the mobile station must notify the coast station or stations concerned that its service is reopening from the moment when such reopening is permitted by the regulations in force in the country where the port of departure is situated.

ARTICLE 37

Distress Signal and Traffic. Alarm, Urgency and Safety Signals

Section I. General

864 § 1. (NEW) In the maritime mobile and aeronautical mobile services, the procedure laid down in this article is obligatory.

865 § 2. No provision of these Regulations shall prevent the use by a mobile station in distress of any means at its disposal to attract attention, make known its position, and obtain help.

866 § 3. (1) The speed of telegraph transmission in cases of distress, urgency or safety must not in general exceed 16 words a minute.

867 (2) The speed of transmission for the alarm signal is indicated in 920.

Section II. Frequencies to Be Used in Case of Distress

868 § 4. (MOD) *Ships.*

(1) In case of distress, the frequency to be used shall be the international distress frequency, that is, 500 kc/s (see **714**); it must preferably be used on class A2 or B emissions.

869 (MOD) (2) In case of distress for radiotelephone stations working in the authorized bands between 1 605 and 2 850 kc/s, the frequency to be used is the distress frequency 2 182 kc/s (see article 34), particularly **815**.

870 (NEW) (3) Ship stations which cannot transmit on the above distress frequencies shall use their normal calling frequency.

871 § 5. (MOD) *Aircraft.*

Any aircraft in distress must transmit the distress call on the frequency on which the land or mobile stations capable of helping it, keep watch. When the call is addressed to stations of the maritime mobile service, the frequencies to be used shall be the international distress frequency 500 kc/s or other watchkeeping frequencies of these stations.

Section III. Distress Signal

872 § 6. (1) In radiotelegraphy, the distress signal consists of the group • • • — — — • • • transmitted as a single signal in which the dashes must be emphasized so as to be distinguished clearly from the dots.

873 (2) In radiotelephony, the distress signal consists of the word MAYDAY pronounced as the French expression "m'aider".

874 § 7. These distress signals indicate that the ship, aircraft, or other vehicle sending the distress signal is threatened by grave and imminent danger and requests immediate assistance.

Section IV. Distress Call

875 § 8. The distress call and message are sent only on the authority of the master or person responsible for the ship, aircraft or other vehicle carrying the mobile station.

876 § 9. (1) The distress call, when sent by radiotelegraphy on 500 kc/s is, as a general rule, preceded by the alarm signal as defined in **920**.

877 (MOD) (2) When circumstances permit, the transmission of the call is separated from the end of the alarm signal by an interval of two minutes. In this case, the alarm signal must be followed immediately by the distress signal • • • — — — • • • sent three times, in order to operate the automatic apparatus mentioned in **931**.

878 § 10. The distress call sent by radiotelegraphy comprises:

—the distress signal transmitted three times;
—the word DE;
—the call sign of the mobile station in distress, sent three times.

879 § 11. (NEW) The distress call, when sent by radiotelephony, is generally preceded by the signal • • • — — — • • • produced by a whistle or any other suitable means.

880 § 12. (NEW) The distress call sent by radiotelephony comprises:

—the distress signal MAYDAY spoken three times;
—the words THIS IS, followed by the identification of the mobile station in distress, the whole repeated three times.

881 § 13. The distress call has absolute priority over other transmissions. All stations which hear it must immediately cease any transmission capable of interfering with the distress traffic and must listen on the frequency used for the emission of the distress call. This call must not be addressed to a particular station and acknowledgment of receipt is not to be given before the distress message is sent.

Section V. Distress Message

882 § 14 (1) The distress call must be followed as soon as possible by the distress message. This message comprises:
—the distress call;
—the name of the ship, aircraft, or vehicle in distress;
—particulars of its position, the nature of the distress and the kind of assistance desired;
—any other information which might facilitate the rescue.

883 (MOD) (2) As a general rule, a ship signals its position in latitude and longitude (Greenwich), using figures for the degrees and minutes, together with one of the words NORTH or SOUTH and one of the words EAST or WEST. The signal ▪ ▬ ▪ ▬ ▪ ▬ is used to separate the degrees from the minutes. When practicable, the true bearing and distance in nautical miles from a known geographical point may be given.

884 (MOD) (3) As a general rule, and if time permits, an aircraft shall transmit in its distress message the following information:
—estimated position and time of the estimate;
—true heading and indicated air speed;
—altitude;
—type of aircraft;
—nature of distress;
—intention of person in command (such as forced alighting on the sea or crash landing).

885 (NEW) (4) As a general rule, an aircraft in flight signals its position:
—if possible by latitude and longitude (Greenwich), using figures for the degrees and minutes, together with one of the words NORTH or SOUTH and one of the words EAST or WEST; or
—by the name of the nearest place, and its approximate distance in relation thereto, together with one of the words NORTH, SOUTH, EAST, or WEST, as the case may be, or, when practicable, by words indicating intermediate directions.

886 § 15. (MOD) After the transmission of its distress message, the mobile station transmits two dashes of approximately 10 second's duration each, followed by its call sign, to permit direction-finding stations to determine its position. This transmission will be repeated at frequent intervals in case of necessity.

887 § 16. (1) The distress message must be repeated at intervals, especially during the period of silence prescribed in **733**, until an answer is received.

888 (2) The alarm signal may also be repeated, if necessary.

889 (3) The intervals must, however, be sufficiently long to allow time for stations preparing to reply to start their sending apparatus.

890 (MOD) (4) When the mobile station in distress receives no answer to a distress message sent on a distress frequency, the message may be repeated on any other available frequency on which attention might be attracted.

891 § 17. (NEW) Immediately before a crash landing, a forced landing (on land or sea) of an aircraft, as well as before total abandonment of a ship or an aircraft, the radio apparatus must, if circumstances permit, be set for continuous emission.

892 § 18. A mobile station which learns that another mobile station is in distress may transmit the distress message in either of the following cases:

893 *a*) the station in distress is not itself in a position to transmit it;

894 *b*) the master or person responsible for the ship, aircraft or other vehicle carrying the station which intervenes, believes that further help is necessary.

895 § 19. (1) Stations of the mobile service which receive a distress message from a mobile station which is, beyond any possible doubt, in their vicinity, must immediately acknowledge receipt (see **913**, **914** and **915**). If the distress call has not been preceded by the alarm signal, these stations may transmit this alarm signal with the permission of the authority responsible for the station (for mobile stations see **565**), taking care not to interfere with the transmission of acknowledgments of receipt sent by other stations.

896 (2) Stations of the mobile service which receive a distress message from a mobile station which, beyond any possible doubt, is not in their vicinity, must allow a short interval of time before acknowledging receipt of the message, in order to permit stations nearer to the mobile station in distress to answer and acknowledge receipt without interference.

897 (NEW) (3) The provisions of **895** and **896** are equally applicable to all stations working in the bands of the mobile service.

Section VI. Distress Traffic

898 § 20. Distress traffic comprises all messages relative to the immediate assistance required by the mobile station in distress.

899 § 21. In distress traffic, the distress signal must be sent before the call and at the beginning of the preamble of any ratiotelegram.

900 § 22. The control of distress traffic is the responsibility of the mobile station in distress or of the mobile station which, by the application of the provisions of **892** and **893**, has sent the distress call. These stations may, however, delegate the control of the distress traffic to another station.

901 § 23. (NEW) (1) The station in distress may impose silence either on all stations of the mobile service in the area or on any station which interferes with the distress traffic. It addresses these instructions "to all stations" or to one station only, according to circumstances. In either case, it uses the service abbreviation QRT followed by the distress signal ▪ ▪ ▪ ▬ ▬ ▬ ▪ ▪ ▪

902 (MOD) (2) If it believes it to be essential, any station of the mobile service near the ship, aircraft or other vehicle in distress, may also impose silence. It employs for this purpose the procedure prescribed in **901**, substituting for the distress signal the word DISTRESS followed by its own call sign.

903 (NEW) (3) The use of the service abbreviation QRT must be reserved, as far as possible, for the mobile station in distress and for the station controlling distress traffic.

904 § 24. (1) Any station which hears a distress call must comply with the provisions of **881**.

905 (2) Any station of the mobile service which has knowledge of distress traffic must follow such traffic, even if it does not take part in it.

906 (3) For the entire duration of distress traffic, it is forbidden for all stations which are aware of this traffic and which are not taking part in it:

907 (MOD) *a*) to transmit on the frequencies on which the distress traffic is taking place;

908 *b*) to use class B emissions.

909 (MOD) (4) A station of the mobile service which, while following distress traffic, is able to continue its normal service, may do so when the distress traffic is well established and on condition that it observes the provisions of **906**, **907** and **908** and does not interfere with the distress traffic.

910 § 25. (NEW) A land station receiving a distress message must without delay take the necessary action to advise the authorities participating in the operation of rescue facilities.

911 § 26. (1) When distress traffic has ceased or when silence is no longer necessary, a station which has controlled such traffic transmits on the distress frequency and if necessary on the frequency used for distress traffic, a message addressed "to all stations" indicating that the distress traffic has ceased.

912 (2) This message takes the following form:

—distress signal;
—call "to all stations" CQ, (three times);
—the word DE;
—call sign of the station sending the message (once);
—time of handing in of the message;
—name and call sign of the mobile station which was in distress;
—service abbreviation QUM.

Section VII. Acknowledgment of Receipt of a Distress Message

913 § 27. The acknowledgment of receipt of a distress message is given in the following form:

—call sign of the mobile station in distress (three times);
—the word DE;
—call sign of the station acknowledging receipt (three times);
—group RRR;
—distress signal.

914 § 28. (1) Every mobile station which acknowledges receipt of a distress message must, on the order of the master or person responsible for the ship, aircraft or other vehicle, transmit, as soon as possible, the following information in the order shown:

—its name;
—its position in the form prescribed in **883** and **885**;
—the speed at which it is proceeding towards the ship, aircraft or other vehicle in distress.

915 (2) Before sending this message, the station must ensure that it will not interfere with the emissions of other stations better situated to render immediate assistance to the station in distress.

Section VIII. Repetition of a Distress Call or a Distress Message

916 § 29. (1) Any station of the mobile service which is not in a position to render assistance and which has heard a distress message which has not been immediately acknowledged, must take all possible steps to attract the attention of stations of the mobile service which are in a position to render assistance.

917 (2) For this purpose, with the approval of the authority responsible for the station, the distress call or the distress message may be repeated. This repetition is made on full power either on the distress frequency or on one of the frequencies which may be used in case of distress (see **868** to **871**). At the same time all necessary steps are taken to notify the authorities who may be able to intervene usefully.

918 (3) In radiotelegraphy, the repetition of the distress call or distress message is generally preceded by the transmission of the alarm signal as defined in **920**. A sufficient interval of time is to be allowed between the transmission of an alarm signal and the repetition of the distress call or distress message, so that mobile stations, which do not keep continuous watch and which are warned by the sounding of their automatic alarm apparatus, have time to go on watch.

919 (4) A station which repeats a distress call or distress message, follows it by the word DE and its own call sign transmitted three times.

Section IX. Alarm Signal

920 § 30. (MOD) (1) The alarm signal shall consist of a series of twelve dashes sent in one minute, the duration of each dash being four seconds and the duration of the interval between two consecutive dashes one second. It may be transmitted by hand but its transmission by means of an automatic instrument is recommended.

921 (MOD) (2) Any ship station working in the band 405 to 535 kc/s which is not provided with an automatic apparatus for the transmission of the alarm signal, must be permanently equipped with a clock, clearly marking the seconds, preferably by means of a sweep hand completing one revolution per minute. This clock must be placed at a point sufficiently visible from the operator's table in order that the operator may, by keeping it in view, easily and correctly time the different elements of the alarm signal.

922 (3) This special signal has for its sole purpose the actuation of the automatic devices giving the alarm. It must be used solely either to announce that a distress call or message is about to follow or to announce the transmission of an urgent cyclone warning; in the latter case it may be used only by the coast stations duly authorized by their government.

923 (4) In cases of distress, the use of the alarm signal is governed by **876**; in the case of an urgent cyclone warning, the transmission of the warning must not begin until two minutes after the end of the alarm signal.

924 § 31. The automatic devices intended for the reception of the alarm signal must fulfill the following conditions:

925 (MOD) *a*) they must respond to the alarm signal transmitted by the telegraphic emissions of at least class A2 or B;

926 (NEW) *b*) they must respond to the alarm signal through interference (provided it is not continuous) caused by atmospherics and powerful signals other than the alarm signal; preferably without any manual adjustment being required during any period of watch maintained by the apparatus;

927 *c*) they must not be actuated by atmospherics or by strong signals other than the alarm signal;

928 (MOD) *d*) they must possess a minimum sensitivity such that with negligible atmospheric interference, they are capable of being operated by the alarm signal transmitted by the emergency (reserve) transmitter of a ship station at any distance from this station up to the normal range fixed for this transmitter by the Convention for the Safety of Life at Sea, and preferably at greater distances;

929 (MOD) *e*) they must give warning of any fault which would prevent the apparatus from performing its normal functions during watch hours.

930 § 32. (MOD) Before an automatic alarm receiver may be approved for use on ships, the administration having jurisdiction over those ships must be satisfied by practical tests made under operating conditions equivalent to those obtaining in practice (including interference, vibration, etc.), that the apparatus complies with the provisions of these Regulations.

931 § 33. The adoption of the alarm signal defined in **920** does not prevent an administration from authorizing the use of an automatic apparatus which complies with the preceding conditions and can be actuated by the distress signal ▪ ▪ ▪ ▬ ▬ ▬ ▪ ▪ ▪.

Section X. Urgency Signal

932 § 34. (1) The urgency signal may be transmitted only on the authority of the master or the person responsible for the ship, aircraft or other vehicle carrying the mobile station.

933 (2) The urgency signal may be transmitted by a land station only with the approval of the responsible authority.

934 § 35. (1) In radiotelegraphy, the urgency signal consists of three repetitions of the group XXX, sent with the letters of each group and the successive groups clearly separated from each other. It is sent before the call.

935 (2) In radiotelephony, the urgency signal consists of three repetitions of the word PAN pronounced as the French word "panne." It is sent before the call.

936 § 36. (1) The urgency signal indicates that the calling station has a very urgent message to transmit concerning the safety of a ship, aircraft or other vehicle or of some person on board or within sight.

937 (2) The urgency signal has priority over all other communications, except distress. All mobile and land stations which hear it must take care not to interfere with the transmission of the message which follows the urgency signal.

938 (MOD) (3) Where the urgency signal is used by a mobile station, it must, as a general rule, be addressed to a specific station.

939 § 37. (MOD) Messages preceded by the urgency signal must, as a general rule, be drawn up in plain language, except in the case of medical messages.

940 § 38. (1) Mobile stations which hear the urgency signal must continue to listen for at least three minutes At the end of this period, if no urgency message has been heard, they may resume their normal service.

941 (2) However, land and mobile stations which are in communication on frequencies other than those used for the transmission of the urgency signal and of the call which follows it may continue their normal work without interruption provided the urgency message is not addressed "to all stations" (CQ).

942 § 39. When the urgency signal has been sent before transmitting a message which is intended for all stations and which calls for action by the stations receiving the message, the station responsible for its transmission must cancel it as soon as it knows that action is no longer necessary. This message of cancellation must likewise be addressed "to all stations" (CQ).

Section XI. Safety Signal

943 § 40. (1) In radiotelegraphy, the safety signal consists of three repetitions of the group TTT, sent with the letters of each group and the successive groups clearly separated from each other. It is sent before the call.

944 (2) In radiotelephony, the word SÉCURITÉ pronounced as the French word "sécurité", repeated three times, is used for the safety signal.

945 § 41. (1) The safety signal indicates that the station is about to transmit a message concerning the safety of navigation or giving important meteorological warnings.

946 (2) The safety signal and the message which follows it are sent on the distress frequency or on one of the frequencies which may be used in case of distress (see **868** to **871**.

947 § 42. (1) With the exception of messages transmitted at fixed times, the safety signal, when it is used in the maritime mobile service, must be transmitted towards the end of the first available period of silence (see **733**); the message is transmitted immediately after the period of silence.

948 (2) In the cases prescribed in **1050, 1053** and **1056**, the safety signal and the message which follows it must be transmitted as soon as possible, but must be repeated as just indicated, at the end of the first period of silence which follows.

949 § 43. (NEW) All stations hearing the safety signal must continue to listen on the frequency on which the safety signal has been transmitted until they are satisfied that the message is of no interest to them. They must, moreover, not make any transmissions likely to interfere with the message.

ARTICLE 38

Order of Priority of Communications in the Mobile Service

950 (MOD) The order of priority of communications in the mobile service is as follows:

1st Distress calls, distress messages and distress traffic.
2nd Communications preceded by the urgency signal.
3rd Communications preceded by the safety signal.
4th Communications relative to radio direction-finding bearings.
5th Radiotelegrams relative to the navigation and safe movement of aircraft.
6th Radiotelegrams relative to the navigation, movements, and needs of ships; weather observation messages destined for an official meteorological service.
7th Government radiotelegrams for which priority right has been claimed.
8th Service radiotelegrams relating to the working of the radiocommunication service or to radiotelegrams previously transmitted.
9th All other communications.

ARTICLE 40

Routing of Radiotelegrams

954 § 1. (MOD) (1) As a general rule, a mobile station which uses emissions of class A2 within the band from 405 to 535 kc/s transmits its radiotelegrams to the nearest coast or aeronautical station. In order to expedite or facilitate the transmission of the radiotelegrams, however, it may transmit them to another mobile station. The latter treats the radiotelegrams so received as if they originated with itself.

955 (MOD) (2) If, however, the mobile station can choose between several coast or aeronautical stations at approximately the same distance, it must give the preference to that which is established on the territory of the country of destination or of normal transit of radiotelegrams. When the station chosen is not the nearest, the mobile station must cease working or must change the frequency or class of emission upon the first request made by the coast or aeronautical station which is actually the nearest, this request being based upon the interference which the working in question causes to the coast or aeronautical station.

956 § 2. (MOD) Mobile stations using emissions of class A1, A2, or A3, outside the band from 405 to 535 kc/s must, as a general rule, give preference to the coast or aeronautical station established on the territory of the country of destination or of the country likely to be the most suitable transit route for radiotelegrams.

957 § 3. (MOD) If the sender of a radiotelegram handed in at a mobile station has indicated the coast or aeronautical station to which he desires his radiotelegram sent, the mobile station must, in order to effect this transmission to the coast or aeronautical station indicated, wait, if necessary, until the conditions specified in **954**, **955** and **956** above are fulfilled.

958 § 4. (NEW) In order to facilitate disposal of traffic, and subject to such restrictions as individual governments may impose, coast stations may, in exceptional circumstances and with discretion, without incurring additional charges, exchange radiotelegrams and service messages relating thereto.

1056 **§ 7. (MOD) Messages containing information concerning the presence of dangerous ice, dangerous wrecks, or any other imminent danger to marine navigation, must be transmitted as soon as possible to other ship stations in the vicinity, and to the appropriate authorities at the first point of the coast with which contact can be established. These transmissions must be preceded by the safety signal.**

APPENDIX 5

Band of Frequencies Required for Certain Types of Radiocommunication

(MOD) The width of the frequency band which is necessary in the overall system, including both the transmitter and the receiver, for the proper reproduction at the receiver of the desired information, does not necessarily indicate the interfering characteristics of an emission.

(NEW) For the determination of this necessary bandwidth, the following table may be considered as a guide.

(NEW) In the formulation of the table, the following working terms have been employed:

B = Telegraph speed in bauds.

$\frac{N}{T}$ = Maximum possible number of black plus white elements to be transmitted per second, in facsimile and television.

M = Maximum modulation frequency expressed in cycles per second.

D = Half the difference between the maximum and minimum values of the instantaneous frequencies; D being greater than $2M$, greater than $\frac{N}{T}$ or greater than B, as the case may be. Instantaneous frequency is the rate of change of phase.

t = Pulse length expressed in seconds.

K = An overall numerical factor which differs according to the emission and depends upon the allowable signal distortion and, in television, the time lost from the inclusion of a synchronizing signal.

Table of Necessary Bandwidths

Description and Class of Emission	Necessary Bandwidth in Cycles per Second	Examples	
		Details	Designation of Emission
	(MOD) I. AMPLITUDE MODULATION		
Continuous wave Telegraphy	BK $K = 5$ for fading circuits,	Morse code at 25 words per minute, $B = 20$, Bandwidth: 100 c/s.	0,1A1
A1	$K = 3$ for non-fading circuits.	Four channel multiplex, 7 unit code, 60 words per minute per channel, $B = 170$, $K = 5$, Bandwidth: 850 c/s.	0.85A1
Telegraphy modulated at audio frequency A2	$BK + 2M$ $K = 5$ for fading circuits. $K = 3$ for non-fading circuits.	Morse code at 25 words per minute with 1 000-cycle tone, $B = 20$, Bandwidth: 2 100 c/s.	2.1A2
Commercial Telephony A3	M, for single sideband.	For ordinary SSB telephony, $M = 3\,000$.	3A3a
	$2M$, for double sideband.	For high-quality SSB telephony, $M = 4\,000$.	4A3a
Broadcasting A3	$2M$	M may vary between 4 000 and 10 000 depending upon the quality desired.	8A3 to 20A3

		Examples	
Description and Class of Emission	Necessary Bandwidth in Cycles per Second	Details	Designation of Emission
Facsimile Carrier modulated by tone and by keying A4	$\frac{KN}{T} + 2M$ $K = 1.5$	The total number of picture elements (black and white) transmitted per second = the circumference of the cylinder (height of picture) × number of lines per unit length × speed of rotation of cylinder in revolutions per second. Diameter of cylinder = 70 mm. Number of lines per mm = 3.77. Speed of rotation 1 turn per second. Frequency of modulation = 1 800 c/s. Bandwidth = 3 600 + 1 242 = 4 842 c/s.	4.84A4
Television A5	$\frac{KN}{T}$ $K = 1.5$ (this allows for synchronization and filter shaping) Note: This band can be appropriately reduced when asymmetrical transmission is employed.	The total number of picture elements (black and white) transmitted per second = the number of lines forming each image × number of elements per line × number of pictures transmitted per second. Number of lines = 500. Number of elements per line = 500. Number of pictures per second = 25. Bandwidth is approximately 9 Mc/s.	9 000A5

(NEW) II. FREQUENCY MODULATION

Description and Class of Emission	Necessary Bandwidth in Cycles per Second	Details	Designation of Emission
Frequency-shift Telegraphy F1	$BK + 2D$ $K = 5$ for fading circuits. $K = 3$ for non-fading circuits.	Four-channel multiplex with 7-unit code. 60 words per minute per channel. $B = 170$ $K = 5$ $D = 425$ Bandwidth: 1 700 c/s.	1.7F1
Commercial Telephony and Broadcasting F3	$2M + 2DK$ For commercial telephony, $K = 1$. For high-fidelity transmission, higher values of K may be necessary.	For an average case of commercial telephony with $D = 15\,000$ $M = 3\,000$ Bandwidth: 36 000 c/s.	36F3
Facsimile F4	$\frac{KN}{T} + 2M + 2D$ $K = 1.5$	(See facsimile, amplitude modulation). Cylinder diameter = 70 mm. Lines per mm = 3.77. Cylinder speed = 1 rps. Modulation tone = 1 800 c/s. $D = 10\,000$ c/s. Bandwidth: 25 000 c/s (approximately)	25F4

(NEW) III. PULSE EMISSIONS

Description and Class of Emission	Necessary Bandwidth in Cycles per Second	Details	Designation of Emission
Unmodulated pulse P0	$2\frac{K}{t}$ K varies from 1 to 10 according to the permissible deviation in each particular case from a rectangular pulse shape. In many cases the value of K does not need to exceed 6.	$t = 3 \times 10^{-6}$ $K = 6$ Bandwidth: 4×10^{6} c/s.	4 000P0

Description and Class of Emission	Necessary Bandwidth in Cycles per Second	Examples	
		Details	Designation of Emission
Modulated pulse P2 or P3	The band width depends upon the particular types of modulation used, many of these being still in the development stage.	—	—

APPENDIX 8

Documents with which Ship and Aircraft Stations must be provided

(See articles 20, 22, 23, 24, 28 and appendix 6)

Section I. For Stations on Board Ships Compulsorily Equipped with a Radiotelegraph Installation:

1st license provided for by article 22;
2nd certificates of the operator or operators;
(MOD) 3rd log (diary of the radio service) in which the following are recorded as they occur, together with the time of their occurrence:
  a) all communications relating to distress traffic in full,
  b) urgency and safety communications,
  c) communications exchanged between the ship station and land or mobile stations,
  d) service incidents of all kinds,
  e) if the ship's rules permit, the position of the ship at least once a day;
4th alphabetical List of Call Signs;
5th List of Coast and Ship Stations;
(NEW) 6th List of Radiolocation Stations;
7th List of Stations peforming Special Services;
8th Radio Regulations and Additional Radio Regulations, also such provisions of the Convention as relate to the radiocommunication service on board ship;
9th telegraph tariffs of the countries for which the station most frequently accepts radiotelegrams;
(NEW) 10th if administrations consider it necessary, the Telegraph Regulations.

(MOD) Section II. For other Radiotelegraph Stations on Ships:

—the documents mentioned in items 1 to 5 of Section I.

(NEW) Section III. For Ship Stations Equipped Solely for Radiotelephony:

1st the documents mentioned in items 1 and 2 of Section I;
2nd the log (diary of the radio service) in which the following are recorded as they occur, together with the time of their occurrence:
  a) a summary of all communications relating to distress, urgency and safety traffic,
  b) a summary of communications exchanged between the ship station and land or mobile stations,
  c) a reference to important service incidents;
3rd documents containing information necessary for the operation of the service.

(NEW) Section IV. For Ship Stations Equipped with Multiple Installations:

1st for each station, if necessary, the documents mentioned in items 1 to 3 of Section I,
2nd for only one of them, the other documents mentioned in Sections I or III, as appropriate.

(MOD) Section V. For Aircraft Stations:

1st the documents mentioned in items 1 and 2 of Section I,
2nd the log (diary of the radio service) as defined in item 3 of Section I, unless administrations have adopted other arrangements for recording all information which the log should contain,
3rd the List of Aeronautical and Aircraft Stations, the List of Radiolocation Stations, or other documents containing official information relating to stations which the aircraft station may use for the execution of its service.

APPENDIX 9

Miscellaneous Abbreviations and Signals to be used in Radiocommunications

(See article 29)

SECTION I. Q CODE

Introduction

1. The series of groups QRA to QUZ listed in this Appendix, is for use by all services.

(NEW) 2. The QAA to QNZ series are reserved for the aeronautical service and the QOA to QQZ series are reserved for the maritime services. These series are not listed in these regulations.

(NEW) 3. Certain abbreviations may be given an affirmative or negative sense by sending "C" or "N" respectively, immediately following the "Q" code abbreviation.

(NEW) 4. The meanings assigned to "Q" code abbreviations may be amplified or completed by the addition of appropriate other groups, call signs, place names, figures, numbers, etc. It is optional to fill in the blanks shown in parentheses. Any data which is filled in where blanks appear should be sent in the same order as shown in the significations.

(NEW) 5. Abbreviations are given the form of a question when followed by a question mark. When an abbreviation is used as a question and is followed by additional or complementary information, the question mark should follow this information.

(NEW) 6. Abbreviations, with numbered alternative significations, must be followed by the appropriate figure to indicate the exact meaning intended. This figure should be sent immediately following the abbreviation.

(NEW) 7. All time should be given in Greenwich mean time (G.M.T.) unless otherwise indicated in the question or reply.

Abbreviations Available for All Services

A. List of Abbreviations in alphabetical order

Abbreviation	Question	Answer or Advise
QRA	What is the name of your station?	The name of my station is . . .
(MOD) QRB	How far approximately are you from my station?	The approximate distance between our stations is . . . nautical miles (*or* kilometres).
(MOD) QRC	By what private enterprise (*or* State Administration) are the accounts for charges for your station settled?	The accounts for charges of my station are settled by the private enterprise . . . (*or* State Administration).
(MOD) QRD	Where are you bound and where are you from?	I am bound for . . . from . . .
(NEW) QRE	What is your estimated time of arrival at . . . (*place*)?	My estimated time of arrival at . . . (*place*) is . . . hrs.
(NEW) QRF	Are you returning to . . . (*place*)?	I am returning to . . . (*place*) *or* Return to . . . (*place*).

Abbre-viation	Question	Answer or Advice
(MOD) QRG	Will you tell me my exact frequency (*or* that of . . .)?	Your exact frequency (*or* that of . . .) is . . . kc/s (*or* Mc/s).
(MOD) QRH	Does my frequency vary?	Your frequency varies.
(MOD) QRI	How is the tone of my transmission?	The tone of your transmission is . . . (1. good; 2. variable; 3. bad).
(MOD) QRK	What is the readability of my signals (*or* those of . . .)?	The readability of your signals (*or* those of . . .) is . . . (1. Unreadable; 2. Readable now and then; 3. Readable, but with difficulty; 4. Readable; 5. Perfectly readable).
QRL	Are you busy?	I am busy (*or* I am busy with . . .). Please do not interfere.
QRM	Are you being interfered with?	I am being interfered with.
QRN	Are you troubled by static?	I am troubled by static.
(MOD) QRO	Shall I increase power?	Increase power.
(MOD) QRP	Shall I decrease power?	Decrease power.
(MOD) QRQ	Shall I send faster?	Send faster (. . . words per minute).
(NEW) QRR	Are you ready for automatic operation?	I am ready for automatic operation. Send at . . . words per minute.
(MOD) QRS	Shall I send more slowly?	Send more slowly (. . . words per minute).
(MOD) QRT	Shall I stop sending?	Stop sending.
QRU	Have you anything for me?	I have nothing for you.
QRV	Are you ready?	I am ready.
(MOD) QRW	Shall In inform . . . that you are calling him on . . . kc/s (*or* Mc/s)?	Please inform . . . that I am calling him on . . . kc/s (*or* Mc/s).
(MOD) QRX	When will you call me again?	I will call you again at . . . hours [on . . . kc/s (*or* Mc/s)].
(MOD) QRY	What is my turn? (*Relates to communication*)	Your turn is Number . . . (*or according to any other indication*). (*Relates to communication.*)
(MOD) QRZ	Who is calling me?	You are being called by . . . [on . . . kc/s (*or* Mc/s)].
(MOD) QSA	What is the strength of my signals (*or* those of . . .)?	The strength of your signals (*or* those of . . .) is . . . (1. Scarcely perceptible; 2. Weak; 3. Fairly good; 4. Good; 5. Very good).
(MOD) QSB	Are my signals fading?	Your signals are fading.
(NEW) QSC	Are you a cargo vessel? (*See article 33, section V*)	I am a cargo vessel.
(MOD) QSD	Is my keying defective?	Your keying is defective.
(MOD) QSG	Shall I send . . . telegrams at a time?	Send . . . telegrams at a time.
(NEW) QSI		I have been unable to break in on your transmission. *or* Will you inform . . . (*Call Sign*) that I have been unable to break in on his transmission [on . . . kc/s (or Mc/s)].

Abbreviation	Question	Answer or Advice
QSJ	What is the charge to be collected per word to . . . including your internal telegraph charge?	The charge to be collected per word to . . . including my internal telegraph charge is . . . francs.
(MOD) QSK	Can you hear me between your signals?	I can hear you between my signals.
QSL	Can you acknowledge receipt?	I am acknowledging receipt.
(MOD) QSM	Shall I repeat the last telegram which I sent you, *or* some previous telegram?	Repeat the last telegram which you sent me [*or* telegram(s) number(s) . . .].
(NEW) QSN	Did you hear me [*or* . . . (call sign)] on . . . kc/s (*or* Mc/s)?	I did hear you [*or* . . . (*call sign*)] on . . . kc/s (*or* Mc/s).
(MOD) QSO	Can you communicate with . . . direct or by relay?	I can communicate with . . . direct (or by relay through . . .).
QSP	Will you relay to . . . free of charge?	I will relay to . . . free of charge.
(NEW) QSQ	Have you a doctor on board [*or* is . . . (name of person) on board]?	I have a doctor on board [*or* . . . (name of person) is on board].
(MOD) QSU	Shall I send or reply on this frequency [*or* on . . . kc/s (*or* Mc/s)] (with emissions of class . . .)?	Send or reply on this frequency [*or* on . . . kc/s (*or* Mc/s)] (with emissions of class . . .).
(MOD) QSV	Shall I send a series of V's on this frequency [*or* . . . kc/s (*or* Mc/s)]?	Send a series of V's on this frequency [or . . . kc/s (*or* Mc/s)].
(MOD) QSW	Will you send on this frequency [or on . . . kc/s (*or* Mc/s)] (with emissions of class . . .)?	I am going to send on this frequency [*or* on . . . kc/s (*or* Mc/s)] (with emissions of class . . .).
(MOD) QSX	Will you listen to . . . [*call sign(s)*] on . . . kc/s (*or* Mc/s)?	I am listening to . . .[*call sign(s)*] on . . . kc/s (*or* Mc/s).
(MOD) QSY	Shall I change to transmission on another frequency?	Change to transmission on another frequency [*or* on . . . kc/s (*or* Mc/s)].
(MOD) QSZ	Shall I send each word or group more than once?	Send each word or group twice (*or* . . . times).
(MOD) QTA	Shall I cancel telegram number . . . as if it had not been sent?	Cancel telegram number . . . as if it had not been sent.
(MOD) QTB	Do you agree with my counting of words?	I do not agree with your counting of words; I will repeat the first letter or digit of each word or group.
(MOD) QTC	How many telegrams have you to send?	I have . . . telegrams for you (*or* for . . .).
(MOD) QTE	What is my TRUE bearing from you?	Your TRUE bearing from me is . . . degrees (at . . . hours).
	or	*or*
(MOD)	What is my TRUE bearing from . . . (*call sign*)?	Your TRUE bearing from . . . (*call sign*) was . . . degrees (at . . . hours).
	or	*or*
(MOD)	What is the TRUE bearing of . . . (*call sign*) from . . . (*call sign*)?	The TRUE bearing of . . . (*call sign*) from . . . (*call sign*) was . . . degrees at . . . hours.
(MOD) QTF	Will you give me the position of my station according to the bearings taken by the direction finding stations which you control? (*see appendix 15*).	The position of your station according to the bearings taken by the direction finding stations which I control was . . . latitude, . . . longitude, class . . . at . . . hours. (*see appendix 15*).

Abbreviation	Question	Answer or Advice
(MOD) QTG	Will you send two dashes of ten seconds each followed by your call sign (repeated . . . times) [on . . . kc/s (*or* Mc/s)]? *or*	I am going to send two dashes of ten seconds each followed by my call sign (repeated . . . times) [on . . . kc/s (*or* Mc/s)]. *or*
(NEW)	Will you request . . . to send two dashes of ten seconds followed by his call sign (repeated . . . times) on . . . kc/s (*or* Mc/s)?	I have requested . . . to send two dashes of ten seconds followed by his call sign (repeated . . . times) on . . . kc/s (*or* Mc/s).
QTH	What is your position in latitude and longitude (*or according to any other indication*)?	My position is . . . latitude . . . longitude (*or according to any other indication*).
(MOD) QTI	What is your TRUE track?	My TRUE track is . . . degrees.
QTJ	What is your speed?	My speed is . . . knots (*or* kilometres per hour).
(NEW)	(*Requests the speed of a ship or aircraft through the water or air respectively.*)	(*Indicates the speed of a ship or aircraft through the water or air respectively.*)
(NEW) QTK	What is the speed of your aircraft in relation to the surface of the earth?	The speed of my aircraft in relation to the surface of the earth is . . . knots (*or* kilometres per hour).
(NEW) QTL	What is your TRUE heading (TRUE course with no wind)?	My TRUE heading is . . . degrees.
(NEW) QTN	At what time did you depart from . . . (*place*)?	I departed from . . . (*place*) at . . . hours.
QTO	Have you left dock (*or* port)? *or*	I have left dock (*or* port). *or*
(NEW)	Are you air-borne?	I am air-borne.
QTP	Are you going to enter dock (*or* port)? *or*	I am going to enter dock (*or* port). *or*
(NEW)	Are you going to alight (*or* land)?	I am going to alight (*or* land).
QTQ	Can you communicate with my station by means of the International Code of Signals?	I am going to communicate with your station by means of the International Code of Signals.
(MOD) QTR	What is the correct time?	The correct time is . . . hours.
(NEW) QTS	Will you send your call sign for . . . minute(s) now (*or* at . . . hours) [on . . . kc/s (*or* Mc/s)] so that your frequency may be measured?	I will send my call sign for . . . minute(s) now (*or* at . . . hours) [on . . . kc/s (*or* (Mc/s)] so that my frequency may be measured.
QTU	What are the hours during which your station is open?	My station is open from . . . to . . . hours.
(NEW) QTV	Shall I stand guard for you on the frequency of . . . kc/s (*or* Mc/s) (from . . . to . . . hours)?	Stand guard for me on the frequency of . . . . kc/s (*or* Mc/s) (from . . . to . . . hours).
(NEW) QTX	Will you keep your station open for further communication with me until further notice (*or* until . . . hours)?	I will keep my station open for further communication with you until further notice (*or* until . . . hours).
(MOD) QUA	Have you news of . . . (*call sign*)?	Here is news of . . . (*call sign*).
(MOD) QUB	Can you give me, in the following order, information concerning: visibility, height of clouds, direction and velocity of ground wind at . . . (*place of observation*)?	Here in the information requested . . .
(MOD) QUC	What is the number (*or other indication*) of the last message you received from me [or from . . . (*call sign*)]?	The number (*or other indication*) of the last message I received from you [or from . . . (*call sign*)] is . . .

Abbreviation	Question	Answer or Advice
(MOD) QUD	Have you received the urgency signal sent by . . . (*call sign of mobile station*)?	I have received the urgency signal sent by . . . (*call sign of mobile station*) at . . . hours.
(MOD) QUF	Have you received the distress signal sent by . . . (*call sign of mobile station*)?	I have received the distress signal sent by . . . (*call sign of mobile station*) at . . . hours.
(MOD) QUG	Will you be forced to alight (*or* land)?	I am forced to alight (*or* land) immediately. *or*
(NEW)		I will be forced to alight (*or* land) at . . . (*position or place*).
QUH	Will you give me the present barometric pressure at sea level?	The present barometric pressure at sea level is . . . (*units*).
(NEW) QUI	Are your navigation lights working?	My navigation lights are working.
(MOD) QUJ	Will you indicate the TRUE course for me to steer towards you (*or* . . .) with no wind?	The TRUE course for you to steer towards me (*or* . . .) with no wind is . . . degrees at . . . hours.
QUK	Can you tell me the condition of the sea observed at . . . (*place or coordinates*)?	The sea at . . . (*place or coordinates*) is . . .
(MOD) QUL	Can you tell me the swell observed at . . . (*place or coordinates*)?	The swell at . . . (*place or coordinates*) is . . .
QUM	Is the distress traffic ended?	The distress traffic is ended.
(NEW) QUN	Will vessels in my immediate vicinity [(*or* in the vicinity of . . . latitude . . . longitude) (or of . . .)] please indicate their position, TRUE course and speed?	My position, TRUE course and speed are . . .
(NEW) QUO	Shall I search for . . . (1. Aircraft; 2. Ship; 3. Survival craft) in the vicinity of . . . latitude . . . longitude (*or according to any other indication*)?	Please search for . . . (1. Aircraft; 2. Ship; 3. Survival craft) in the vicinity of . . . latitude . . . lontigude (*or according to any other indication*).
(NEW) QUP	Will you indicate your position by . . . (1. Searchlight; 2. Black smoke trail; 3. Pyrotechnic lights)?	My position is indicated by . . . (1. Searchlight; 2. Black smoke trail; 3. Pyrotechnic lights).
(NEW) QUQ	Shall I train my searchlight nearly vertical on a cloud, occulting if possible and, if your aircraft is seen, deflect the beam up wind and on the water (*or* land) to facilitate your landing?	Please train your searchlight on a cloud, occulting if possible and, if my aircraft is seen or heard, deflect the beam up wind and on the water (*or* land) to facilitate my landing.
(NEW) QUR	Have survivors . . . (1. Received survival equipment; 2. Been picked up by rescue vessel; 3. Been reached by ground rescue party)?	Survivors . . . (1. Are in possession of survival equipment dropped by . . .; 2. Have been picked up by rescue vessel; 3. Have been reached by ground rescue party).
(NEW) QUS	Have you sighted survivors or wreckage? If so, in what position?	Have sighted . . . (1. Survivors in water; 2. Survivors on rafts; 3. Wreckage) in position . . . latitude . . . longitude (*or according to any other indication*).

Abbreviation	Question	Answer or Advice
(NEW) QUT	Is position of incident marked?	Position of incident is marked (by . . .).
(NEW) QUU	Shall I home ship or aircraft to my position?	Home ship or aircraft . . . [1. . . . (*call sign*) to your position by transmitting your call sign and long dashes on . . . kc/s (*or* Mc/s); 2. . . . (*call sign*) by transmitting on . . . kc/s (*or* Mc/s) courses to steer to reach you].
(NEW) QUV	What is my MAGNETIC bearing from you (*or* from . . .)? (*This signal, in general, will not be used in the Maritime Mobile Service.*)	Your MAGNETIC bearing from me (*or* from . . .) was . . . degrees at . . . hours. (*This signal, in general, will not be used in the Maritime Mobile Service.*)
(NEW) QUX	Will you indicate the MAGNETIC course for me to steer towards you (*or* . . .) with no wind? (*This signal, in general, will not be used in the Maritime Mobile Service.*)	The MAGNETIC course for you to steer to reach me (*or* . . .) with no wind was . . . degrees at . . . hours. (*This signal, in general, will not be used in the Maritime Mobile Service.*)

B. List of Signals According to the Nature of Questions, Answer or Advice

Name

QRA	What is the name of your station?	The name of my station is . . .

Route

(MOD) QRD	Where are you bound and where are you from?	I am bound for . . . from . . .

Position

(MOD) QRB	How far approximately are you from my station?	The approximate distance between our stations is . . . nautical miles (*or* kilometres).
QTH	What is your position in latitude and longitude (*or according to any other indication*)?	My position is . . . latitude . . . longitude (*or according to any other indication*).
(NEW) QTN	At what time did you depart from . . . (place)?	I departed from . . . (place) at . . . hours.

Quality of Signals

(MOD) QRI	How is the tone of my transmission?	The tone of your transmission is . . . (1. Good; 2. Variable; 3. Bad).
(MOD) QRK	What is the readability of my signals (or those of . . .)?	The readability of your signals (*or* those of . . .) is . . . (1. Unreadable; 2. Readable now and then; 3. Readable, but with difficulty; 4. Readable; 5. Perfectly readable).

Strength of Signals

(MOD) QRO	Shall I increase power?	Increase power.
(MOD) QRP	Shall I decrease power?	Decrease power.
(MOD) QSA	What is the strength of my signals (*or* those of . . .)?	The strength of your signals (*or* those of . . .) is . . . (1. Scarcely perceptible; 2. Weak; 3. Fairly good; 4. Good; 5. Very good).

Abbreviation	Question	Answer or Advice
(MOD) QSB	Are my signals fading?	Your signals are fading.
	Keying	
(MOD) QRQ	Shall I send faster?	Send faster (. . . words per minute).
(NEW) QRR	Are you ready for automatic operation?	I am ready for automatic operation. Send at . . . words per minute.
(MOD) QRS	Shall I send more slowly?	Send more slowly (. . . words per minute).
(MOD) QSD	Is my keying defective?	Your keying is defective.
	Interference	
QRM	Are you being interfered with?	I am being interfered with.
QRN	Are you troubled by static?	I am troubled by static.
	Adjustment of Frequency	
(MOD) QRG	Will you tell me my exact frequency (*or* that of . . .)?	Your exact frequency (*or* that of . . .) is . . . kc/s (*or* Mc/s).
(MOD) QRH	Does my frequency vary?	Your frequency varies.
(NEW) QTS	Will you send your call sign for . . . minute(s) now (*or* at . . . hours) [on . . . kc/s (*or* Mc/s)] so that your frequency may be measured?	I will send my call sign for . . . minute(s) now (*or* at . . . hours) [on . . . kc/s (*or* Mc/s)] so that my frequency may be measured.
	Choice of Frequency and/or Class of Emission	
(NEW) QSN	Did you hear me [*or* . . . (call sign)] on . . . kc/s (*or* Mc/s)?	I did hear you [*or* . . . (call sign)] on . . . kc/s (*or* Mc/s).
(MOD) QSU	Shall I send or reply on this frequency [*or* on . . . kc/s (*or* Mc/s)] (with emissions of class . . .)?	Send or reply on this frequency [*or* on . . . kc/s (*or* Mc/s)] (with emissions of class . . .).
(MOD) QSV	Shall I send a series of V's on this frequency [*or* . . . kc/s (*or* Mc/s)]?	Send a series of V's on this frequency [*or* . . . kc/s (*or* Mc/s)].
(MOD) QSW	Will you send on this frequency [*or* on . . . kc/s (*or* Mc/s)] (with emissions of class . . .)?	I am going to send on this frequency [*or* on . . . kc/s (*or* Mc/s)] (with emissions of class . . .).
(MOD) QSX	Will you listen to . . . [call sign(s)] on . . . kc/s (*or* Mc/s)?	I am listening to . . . [call sign(s)] on . . . kc/s (*or* Mc/s).
	Change of Frequency	
(MOD) QSY	Shall I change to transmission on another frequency?	Change to transmission on another frequency [*or* . . . kc/s (*or* Mc/s)].
	Establishing Communication	
QRL	Are you busy?	I am busy (*or* I am busy with . . .). Please do not interfere.
QRV	Are you ready?	I am ready.
(MOD) QRX	When will you call me again?	I will call you again at . . . hours (on . . . kc/s) (*or* Mc/s).
(MOD) QRY	What is my turn? (*Relates to communication.*)	Your turn is Number . . . (*or according to any other indication*). (*Relates to communication.*)
(MOD) QRZ	Who is calling me?	You are being called by . . . [on . . . kc/s (*or* Mc/s)].

Abbreviation	Question	Answer or Advice
(NEW) QSC	Are you a cargo vessel? (*See article 33, section V*).	I am a cargo vessel.
QTQ	Can you communicate with my station by means of the International Code of Signals?	I am going to communicate with your station by means of the International Code of Signals.
	Time	
(MOD) QTR	What is the correct time?	The correct time is . . . hours.
QTU	What are the hours during which your station is open?	My station is open from . . . to . . . hours.
	Charges	
(MOD) QRC	By what private enterprise (*or* State Administration) are the accounts for charges for your station settled?	The accounts for charges of my station are settled by the private enterprise . . . (*or* State Administration).
QSJ	What is the charge to be collected per word to . . . including your internal telegraph charge?	The charge to be collected per word to . . . including my internal telegraph charge is . . . francs.
	Transit	
(MOD) QRW	Shall I inform . . . that you are calling him on . . . kc/s (*or* Mc/s)?	Please inform . . . that I am calling him on . . . kc/s (*or* Mc/s).
(MOD) QSO	Can you communicate with . . . direct or by relay?	I can communicate with . . . direct (or by relay through . . .).
QSP	Will you relay to . . . free of charge?	I will relay to . . . free of charge.
(NEW) QSQ	Have you a doctor on board [*or* is . . . (name of person) on board]?	I have a doctor on board [*or* . . . (name of person) is on board].
(MOD) QUA	Have you news of . . . (*call sign*)?	Here is news of . . . (*call sign*).
(MOD) QUC	What is the number (*or other indication*) of the last message you received from me [or from . . . (*call sign*)]?	The number (*or other indication*) of the last message I received from you [or from . . . (*call sign*)] is . . .
	Exchange of Correspondence	
QRU	Have you anything for me?	I have nothing for you.
(MOD) QSG	Shall I send . . . telegrams at a time?	Send . . . telegrams at a time.
(NEW) QSI		I have been unable to break in on your transmission. *or* Will you inform . . . (*Call Sign*) that I have been unable to break in on his transmission [on . . . kc/s (or (Mc/s)].
(MOD) QSK	Can you hear me between your signals?	I can hear you between my signals.
QSL	Can you acknowledge receipt?	I am acknowledging receipt.
(MOD) QSM	Shall I repeat the last telegram which I sent you, *or* some previous telegram?	Repeat the last telegram which you sent me [*or* telegram(s) number(s) . . .].
(MOD) QSZ	Shall I send each word or group more than once?	Send each word or group twice (*or* . . . times).
(MOD) QTA	Shall I cancel telegram number . . . as if it had not been sent?	Cancel telegram number . . . as if it had not been sent.
(MOD) QTB	Do you agree with my counting of words?	I do not agree with your counting of words; I will repeat the first letter or digit of each word or group.

Abbreviation	Question	Answer or Advice
(MOD) QTC	How many telegrams have you to send?	I have . . . telegrams for you (*or* for . . .).
(NEW) QTV	Shall I stand guard for you on the frequency of . . . kc/s (*or* Mc/s) (from . . . to . . . hours)?	Stand guard for me on the frequency of . . . kc/s (*or* Mc/s) (from . . . to . . . hours).
(NEW) QTX	Will you keep your station open for further communication with me until further notice (*or* until . . . hours)?	I will keep my station open for further communication with you until further notice (*or* until . . . hours).
	Movement	
(NEW) QRE	What is your estimated time of arrival at . . . (*place*)?	My estimated time of arrival at . . . (*place*) is . . . hrs.
(NEW) QRF	Are you returning to . . . (*place*)?	I am returning to . . . (*place*). *or* Return to . . . (*place*).
(MOD) QTI	What is your TRUE track?	My TRUE track is . . . degrees.
QTJ	What is your speed? (*Requests the speed of a ship or aircraft through the water or air respectively.*)	My speed is . . . knots (*or* kilometres per hour). (*Indicates the speed of a ship or aircraft through the water or air respectively.*)
(NEW) QTK	What is the speed of your aircraft in relation to the surface of the earth?	The speed of my aircraft in relation to the surface of the earth is . . . knots (*or* kilometres per hour).
(NEW) QTL	What is your TRUE heading (TRUE course with no wind)?	My TRUE heading is . . . degrees.
(NEW) QTN	At what time did you depart from . . . (*place*)?	I departed from . . . (*place*) at . . . hours.
QTO	Have you left dock (*or* port)? *or*	I have left dock (*or* port). *or*
(NEW)	Are you air-borne?	I am air-borne.
QTP	Are you going to enter dock (*or* port)? *or*	I am going to enter dock (*or* port). *or*
(NEW)	Are you going to alight (*or* land)?	I am going to alight (*or* land).
(MOD) QUG	Will you be forced to alight (*or* land)?	I am forced to alight (*or* land) immediately. *or* I will be forced to alight (*or* land) at . . . (*position or place*).
(MOD) QUJ	Will you indicate the TRUE course for me to steer towards you (*or* . . .) with no wind?	The TRUE course for you to steer towards me (or . . .) with no wind is . . . degrees at . . . hours.
(NEW) QUN	Will vessels in my immediate vicinity [(*or* in the vicinity of . . . latitude . . . longitude) (*or* of . . .)] please indicate their position, TRUE course and speed?	My position, TRUE course and speed are . . .
(NEW) QUX	Will you indicate the MAGNETIC course for me to steer towards you (*or* . . .) with no wind? (*This signal, in general, will not be used in the Maritime Mobile Service.*)	The MAGNETIC course for you to steer to reach me (*or* . . .) with no wind was . . . degrees at . . . hours. (*This signal, in general, will not be used in the Maritime Mobile Service.*)
	Meteorology	
(MOD) QUB	Can you give me, in the following order, information concerning: visibility, height of clouds, direction and velocity of ground wind at . . . (*place of observation*)?	Here is the information requested . . .

	Abbreviation	Question	Answer or Advice
	QUH	Will you give me the present barometric pressure at sea level?	The present barometric pressure at sea level is . . . (*units*).
	QUK	Can you tell me the condition of the sea observed at . . . (*place or coordinates*)?	The sea at . . . (*place or coordinates*) is . . .
(MOD)	QUL	Can you tell me the swell observed at . . . (*place or coordinates*)?	The swell at . . . (*place or coordinates*) is . . .
		Radio Direction-finding	
(MOD)	QTE	What is my TRUE bearing from you?	Your TRUE bearing from me is . . . degrees at . . . hours).
		or	*or*
(MOD)		What is my TRUE bearing from . . . (*call sign*)?	Your TRUE bearing from . . . (*call sign*) was . . . degrees at . . . hours.
		or	*or*
(MOD)		What is the TRUE bearing of . . . (*call sign*) from . . . (*call sign*)?	The TRUE bearing of . . . (*call sign*) from . . . (*call sign*) was . . . degrees at . . . hours.
(MOD)	QTF	Will you give me the position of my station according to the bearings taken by the direction finding stations which you control? (*See Appendix 15.*)	The position of your station according to the bearings taken by the direction finding stations which I control was . . . latitude, . . . longitude, class . . . at . . . hours. (*See Appendix 15.*)
(MOD)	QTG	Will you send two dashes of ten seconds each followed by your call sign (repeated . . . times) [on . . . kc/s (*or* Mc/s)]?	I am going to send two dashes of ten seconds each followed by my call sign (repeated . . . times) [on . . . kc/s (*or* Mc/s)].
		or	*or*
(NEW)		Will you request . . . to send two dashes of ten seconds followed by his call sign (repeated . . . times) on . . . kc/s (*or* Mc/s)?	I have requested . . . to send two dashes of ten seconds followed by his call sign (repeated . . . times) on . . . kc/s (*or* Mc/s).
(NEW)	QUV	What is my MAGNETIC bearing from you (*or* from . . .)? (*This signal, in general, will not be used in the Maritime Mobile Service.*)	Your MAGNETIC bearing from me (*or* from . . .) was . . . degrees at . . . hours. (*This signal, in general, will not be used in the Maritime Mobile Service.*)
		Suspension of Work	
(MOD)	QRT	Shall I stop sending?	Stop sending.
		Urgency	
(MOD)	QUD	Have you received the urgency signal sent by . . . (*call sign of mobile station*)?	I have received the urgency signal sent by . . . (*call sign of mobile station*) at . . . hours.
(MOD)	QUG	Will you be forced to alight (*or* land)?	I am forced to alight (*or* land) immediately.
			or
(NEW)			I will be forced to alight (*or* land) at . . . (*position or place*).
		Distress	
(MOD)	QUF	Have you received the distress signal sent by . . . (*call sign of mobile station*)?	I have received the distress signal sent by . . . (*call sign of mobile station*) at . . . hours.
	QUM	Is the distress traffic ended?	The distress traffic is ended.
		Search and Rescue	
(NEW)	QUI	Are your navigation lights working?	My navigation lights are working.

Abbreviation	Question	Answer or Advice
(NEW) QUN	Will vessels in my immediate vicinity [(or in the vicinity of . . . latitude . . . longitude) (*or* of . . .)] please indicate their position, TRUE course and speed?	My position, TRUE course and speed are . . .
(NEW) QUO	Shall I search for . . . (1. Aircraft; 2. Ship; 3. Survival craft) in the vicinity of . . . latitude . . . longitude (*or according to any other indication*)?	Please search for . . . (1. Aircraft; 2. Ship; 3. Survival craft) in the vicinity of . . . latitude . . . longitude (*or according to any other indication*).
(NEW) QUP	Will you indicate your position by . . . (1. Searchlight; 2. Black smoke trail; 3. Pyrotechnic lights)?	My position is indicated by . . . (1. Searchlight; 2. Black smoke trail; 3. Pyrotechnic lights).
(NEW) QUQ	Shall I train my searchlight nearly vertical on a cloud, occulting if possible and, if your aircraft is seen, deflect the beam up wind and on the water (*or* land) to facilitate your landing?	Please train your searchlight on a cloud, occulting if possible and, if my aircraft is seen or heard, deflect the beam up wind and on the water (*or* land) to facilitate my landing.
(NEW) QUR	Have survivors . . . (1. Received survival equipment; 2. Been picked up by rescue vessel; 3. Been reached by ground rescue party)?	Survivors . . . (1. Are in possession of survival equipment dropped by . . .; 2. Have been picked up by rescue vessel; 3. Have been reached by ground rescue party).
(NEW) QUS	Mave you sighted survivors or wreckage? If so, in what position?	Have sighted . . . (1. Survivors in water; 2. Survivors on rafts; 3. Wreckage) in position . . . latitude . . . longitude (*or according to any other indication*).
(NEW) QUT	Is position of incident marked?	Position of incident is marked (by . . .).
(NEW) QUU	Shall I home ship or aircraft to my position?	Home ship or aircraft . . . [1. . . . (*call sign*) to your position by transmitting your call sign and long dashes on . . . kc/s (*or* Mc/s); 2. . . . (*call sign*) by transmitting on . . . kc/s (*or* Mc/s) courses to steer to reach you].

SECTION II. MISCELLANEOUS ABBREVIATIONS AND SIGNALS

	Abbreviation or Signal	Definition
	AA	All after . . . (***used after a question mark to request a repetition***).
	AB	All before . . . (***used after a question mark to request a repetition***).
	ABV	Repeat (*or* I repeat) the figures in abbreviated form.
(NEW)	ADS	Address (***used after a question mark to request a repetition***).
(NEW HERE)	$\overline{\text{AR}}$	End of transmission (• ▬ • ▬ • ***to be sent as one signal***).
	$\overline{\text{AS}}$	Waiting period (• ▬ • • • ***to be sent as one signal***).

	Abbreviation or Signal	Definition
(NEW)	BK	Signal used to interrupt a transmission in progress.
	BN	All between . . . and . . . (*used after a question mark to request a repetition*).
	BQ	A reply to an RQ
	C	Yes.
	CFM	Confirm (*or* I confirm).
	CL	I am closing my station.
	COL	Collate (*or* I collate).
(NEW HERE)	CP	General call to two or more specified stations (*see article 32*).
(NEW HERE)	CQ	General call to all stations (*see article 31*).
(MOD)	CS	Call sign (*used to request a call sign*).
	DB	I cannot give you a bearing, you are not in the calibrated sector of this station.
	DC	The minimum of your signal is suitable for the bearing.
(MOD)	DF	Your bearing at . . . (*time*) was . . . degrees, in the doubtful sector of this station, with a possible error of . . . degrees.
(MOD)	DG	Please advise me if you note an error in the bearing given.
(MOD)	DI	Bearing doubtful in consequence of the bad quality of your signal.
(MOD)	DJ	Bearing doubtful because of interference.
	DO	Bearing doubtful. Ask for another bearing later [*or at* . . . (*time*)].
(MOD)	DP	Possible error of bearing may amount to . . . degrees.
(MOD)	DS	Adjust your transmitter, the minimum of your signal is too broad.
(MOD)	DT	I cannot furnish you with a bearing; the minimum of your signal is too broad.
(MOD)	DY	This station is not able to determine the sense of the bearing. What is your approximate direction relative to this station?
	DZ	Your bearing is reciprocal. (*To be used only by the control station of a group of direction-finding stations when it is addressing stations of the same group.*)
(NEW HERE)	DE	Used to separate the call sign of the station called from the call sign of the calling station.
(MOD)	ER	Here . . .
(NEW)	ETA	Estimated time of arrival.
	ITP	The punctuation counts.
(MOD)	JM	Makes a series of dashes if I may transmit. Make a series of dots to stop my transmission (*not to be used on 500 kc/s except in cases of distress*).
(NEW HERE)	K	Invitation to transmit.
(MOD)	MN	Minute (*or* Minutes).
(MOD)	MSG	Prefix indicating a message to or from the master of a ship concerning its operation or navigation.
	N	No.
(MOD)	NIL	I have nothing to send to you.
(MOD)	NW	Now.
(MOD)	OK	We agree (*or* It is correct).
(MOD)	P	Prefix indicating a private radiotelegram.
	PBL	Preamble (*used after a question mark to request a repetition*).

	Abbreviation or Signal	Definition
(NEW)	PTR	Used by a coast station to request the position and next port of call of a mobile station. (*See* **700.**)
(NEW HERE)	R	Received.
	REF	Reference to . . . (*or* Refer to . . .).
(MOD)	RPT	Repeat (*or* I repeat) (*or* Repeat . . .).
(NEW)	RQ	Indication of a request.
	SIG	Signature (*used after a question mark to request a repetition*).
(NEW HERE)	SOS	Distress Signal (• • • ▬ ▬ ▬ • • • *to be sent as one signal*).
(MOD)	SS	Indicator preceding the name of a ship station.
(MOD)	SVC	Prefix indicating a service telegram.
(NEW)	SYS	Refer to your service telegram.
	TFC	Traffic.
(MOD)	TR	Used as a prefix to indicate reply to PTR.
(NEW HERE)	TTT	This group when sent three times constitutes the safety signal (*see* **943**).
(MOD)	TU	Thank you.
	TXT	Text (*used after a question mark to request a repetition*).
(NEW HERE)	VA	End of work (• • • ▬ • ▬ *to be sent as one signal*).
(MOD)	W	Word(s) *or* [Group(s)].
	WA	Word after . . . (*used after a question mark to request a repetition*).
	WB	Word before . . . (*used after a question mark to request a repetition*).
(NEW HERE)	XXX	This group when sent three times constitutes the urgency signal (*see* **934**).

APPENDIX 13

Hours of Service for Ships in the Second Category

(See articles 20 and 35)

SECTION I. TABLE

Zones	Western Limits	Eastern Limits	Hours of Service (Greenwich mean time) (G.M.T.)			
			8 hours (H8)		16 hours (H16)	
			from	to	from	to
A Eastern Atlantic Ocean, Mediterranean, North Sea, Baltic.	Meridian of 30° W., Coast of Greenland.	Meridian of 30° E. to the South of the Coast of Africa, Eastern limits of the Mediterranean, of the Black Sea, and of the Baltic, 30° E. to the North of Norway.	8h. 12h. 16h. 20h.	10h. 14h. 18h. 22h.	0h. 8h. 16h. 20h.	6h. 14h. 18h. 22h.
B Western Indian Ocean, Eastern Arctic Sea.	Eastern Limit of Zone A.	Meridian of 80° E., Western Coast of Ceylon to Adam's Bridge, thence Westward round the coast of India.	4h. 8h. 12h. 16h.	6h. 10h. 14h. 18h.	0h. 4h. 12h. 16h. 20h.	2h. 10h. 14h. 18h. 24h.

Zones	Western Limits	Eastern Limits	Hours of Service (Greenwich mean time) (G.M.T.)			
			8 hours (H8)		16 Hours (H16)	
			from	to	from	to
C Eastern Indian Ocean, China Sea, Western Pacific Ocean.	Eastern Limit of Zone B.	Meridian of 160° E.	0h. 4h. 8h. 12h.	2h. 6h. 10h. 14h.	0h. 8h. 12h. 16h.	6h. 10h. 14h. 22h.
D Central Pacific Ocean.	Eastern Limit of Zone C.	Meridian of 140° W.	0h. 4h. 8h. 20h.	2h. 6h. 10h. 22h.	0h. 4h. 8h. 12h. 20h.	2.h 6h. 10h. 18h. 24h.
E Eastern Pacific Ocean.	Eastern Limit of Zone D.	Meridian of 90° W. as far as the Coast of Central America, then the West Coast of Central America and North America.	0h. 4h. 6h. 20h.	2h. 6h. 18h. 22h.	0h. 4h. 8h. 16h.	2h. 6h. 14h. 22h.
F Western Atlantic Ocean and Gulf of Mexico.	Meridian of 90° W., Gulf of Mexico, East Coast of North America.	Meridian of 30° W., Coast of Greenland.	0h. 12h. 16h. 20h.	2h. 14h. 18h. 22h.	0h. 4h. 12h. 20h.	2h. 10h. 18h. 22h.

APPENDIX 15

Procedure for Obtaining Radio Direction-Finding Bearings and Positions

(See article 44)

Section I. General Instructions

§ 1. (MOD) Before calling one or more direction-finding stations for the purpose of asking for a bearing or position, a mobile station must ascertain from the List of Stations:

a) the call signs of the stations to be called to obtain the desired bearings or position;

b) the frequency on which the radio direction-finding stations keep watch, and the frequency or frequencies on which they take bearings;

c) the radio direction-finding stations which, being linked by special circuits, can be grouped with the radio direction-finding station to be called.

§ 2. The procedure to be followed by the mobile station depends on varying circumstances. Generally, the following must be taken into account:

a) If the radio direction-finding stations do not keep watch on the same frequency (whether it be the frequency on which bearings are taken or another frequency), a separate request for the bearings must be made to each station or group of stations using a given frequency.

b) If all the radio direction-finding stations concerned keep watch on the same frequency, and if they are able to take bearings on a common frequency (which may be different from the listening frequency), the mobile station must call all of them at the same time, in order that these stations may take simultaneous bearings on the same transmission.

c) (MOD) If several radio direction-finding stations are grouped by means of special circuits, only one of them, the radio direction-finding control station, must be called even if all are furnished with transmitting apparatus. In that case, however, the mobile station must, if appropriate, specify in the call, by means of call signs, the radio direction-finding stations from which it wishes to obtain bearings.

§ 3. (MOD) The List of Radiolocation Stations contains information relating to:

a) the type of signal and class of emission to be used for obtaining the bearings;

b) the duration of the transmission to be made by the mobile station; and

c) the time used by the radio direction-finding station in question, if different from Greenwich mean time (G.M.T.).

Section II. Rules of Procedure

§ 4. (NEW) The following rules of procedure are based on the use of radiotelegraphy. For radiotelephony, appropriate phrases may replace the service abbreviations.

§ 5. *To obtain a bearing or course.*

(1) (MOD) The mobile station calls the radio direction-finding station or the radio direction-finding control station on the listening frequency indicated in the List of Stations. Depending on the type of information desired, the calling station transmits the appropriate service abbreviation followed, if the radio direction-finding station is a mobile station, by the service abbreviation QTH? It indicates, if necessary, the frequency on which it is going to transmit to enable its bearing to be taken, and then awaits instructions.

(2) (MOD) The radio direction-finding station called requests the calling station, by means of the appropriate service abbreviation, to transmit for the bearing. If necessary, it indicates the frequency to be used for this purpose and the number of times the transmission is to be repeated.

(3) (MOD) After having changed, if necessary, to its new transmitting frequency, the calling station transmits two dashes of approximately ten seconds each, followed by its call sign. It repeats this signal as often as the radio direction-finding station requires.

(4) (MOD) The radio direction-finding station determines the direction and, if possible, the sense of the bearing, and its classification [see (9)].

(5) If the radio direction-finding station is not satisfied with the operation, it requests the calling station to repeat the transmission described under (3).

(6) (MOD) The radio direction-finding station transmits the information to the calling station in the following order:

a) the appropriate service abbreviation;

b) three digits indicating the true bearing or the true course from the radio direction-finding station;

c) class of bearing;

d) time of observation;

e) if the radio direction-finding station is mobile, its own position in latitude and longitude, preceded by the service abbreviation QTH.

(7) (MOD) As soon as the calling station has received the result of the observation, if it is considered necessary to obtain confirmation, it repeats back the message. The radio direction-finding station then confirms that the repetition is correct or, if necessary, corrects it by repeating the message. When the radio direction-finding station is sure that the calling station has received the message correctly, it transmits the signal "end of work." The calling station repeats this signal as an indication that the operation is finished.

(8) (NEW) In the absence of information to the contrary, the calling station assumes that the sense of the bearing was determined. If the radio direction-finding station has not determined the sense, it indicates this in the information transmitted, or reports the bearing and its reciprocal.

(9) (NEW) According to its estimate of the accuracy of the observation, the radio direction-finding station classifies the bearing in one of the three following classes:

Class A: bearings which the operator may reasonably consider to be accurate to within ± 2° (two degrees);
Class B: bearings which the operator may reasonably consider to be accurate to within ± 5° (five degrees);
Class C: bearings which the operator may reasonably consider to be accurate to within ± 10° (ten degrees).

§ 6. *To obtain a position determined by two or more radio direction-finding stations organized as a group.*

(1) (MOD) If the calling station wishes to be informed of its position by a group of radio direction-finding stations, it calls the control station as is indicated in § 5 (1) above, and requests a position by means of the appropriate service abbreviation.

(2) (MOD) the control station replies to the call and, when the radio direction-finding stations are ready, requests, by means of the appropriate service abbreviation, the calling station to transmit. When the position has been determined, it is transmitted by the control station to the calling station in the form indicated in § 5 (6).

(3) (NEW) According to its estimate of the accuracy of the observation, the control station classifies the position in one of the three following classes:

Class A: positions which the operator may reasonably expect to be accurate to within 5 nautical miles;
Class B: positions which the operator may reasonably expect to be accurate to within 20 nautical miles;
Class C: positions which the operator may reasonably expect to be accurate to within 50 nautical miles.

§ 7. (MOD) *To obtain simultaneous bearings from two or more radio direction-finding stations organized as a group.*

On a request for bearings, the control station of a group of radio direction-finding stations proceeds as indicated in § 6 above. It finally transmits the bearings as observed by each station of the group, each bearing being preceded by the call sign of the station which observed it.

ARTICLE 8

Doubtful Reception. Transmission by "Ampliation" Long-distance Radiocommunications

2114 § 1. (1) In the mobile service, when communication becomes difficult, the two stations in communication make every effort to complete the radiotelegram in course of transmission. The receiving station may request not more than two repetitions of a radiotelegram of which the reception is doubtful. If this triple transmission is ineffective, the radiotelegram is kept on hand in case a favourable opportunity for completing its transmission occurs.

2115 (2) If the transmitting station considers that it will not be possible to re-establish communication with the receiving station within twenty-four hours, it proceeds as follows:

2116 a) *If the transmitting station is a mobile station,* it immediately informs the sender of the reason for the non-transmission of his radiotelegram. The sender may then request:

2117 —that the radiotelegram be transmitted through another land station or through other mobile stations; or

2118 —that the radiotelegram be held until it can be transmitted without additional charge; or

2119 —that the radiotelegram be cancelled.

2120 b) *If the transmitting station is a land station,* it applies the provisions of article 7 to the radiotelegram.

2121 § 2. When a mobile station subsequently transmits a radiotelegram thus held to the land station which incompletely received it, this new transmission must bear the service instruction "ampliation" in the preamble of the radiotelegram. If the radiotelegram is transmitted to another land station subject to the same administration or the same private enterprise, the new transmission must bear the service instruction "ampliation via . . . " (insert here the call sign of the land station to which the radiotelegram was transmitted in the first instance) and the administration or private enterprise in question may claim only the charges relating to a single transmission. The "other land station" which thus forwards the radiotelegram may claim from the mobile station of origin any additional charges resulting from the transmission of the radiotelegram over the general communication network between itself and the office of destination.

2122 § 3. When the land station designated in the address as the station by which the radiotelegram is to be forwarded cannot reach the mobile station of destination, and has reason to believe that such mobile station is within range of another land station of the administration or private enterprise to which it is itself subject, it may, if no additional charge is incurred thereby, forward the radiotelegram to this other land station.

2123 § 4. (1) A station of the mobile service which has received a radiotelegram and has been unable to acknowledge its receipt in the usual way, must take the first favourable opportunity to give such acknowledgment.

2124 (2) When the acknowledgment of receipt of a radiotelegram transmitted between a mobile station and a land station cannot be given direct, it is forwarded through another mobile or land station, if the latter is able to communicate with the station which has transmitted the radiotelegram in question. In any case no additional charge must result.

2125 § 5. (1) Administrations reserve the right to organize a long-distance radiocommunication service between land stations and mobile stations, with deferred acknowledgment of receipt or without any acknowledgment of receipt.

2126 (2) When there is doubt about the accuracy of any part of a radiotelegram transmitted under either of these systems, the indication "doubtful reception" is entered on the copy delivered to the addressee, and the doubtful words or groups of words are underlined. If words are missing, blanks are left in the places where these words should be.

2127 (3) In the long-distance radiocommunication service with deferred acknowledgment of receipt, when the transmitting land station has not, within a period of 5 days, received the acknowledgment of receipt of a radiotelegram sent by it, the station notifies the office of origin. The reimbursement of the land station and ship or aircraft charges must be postponed until the office of origin has ascertained from the land station in question that an acknowledgment of receipt has not been received subsequently, within a period not exceeding one month.

2128 (NEW) (4) Each administration designates the long-distance land station or stations for which its mobile stations keep watch.

ARTICLE 9

Retransmission by Stations of the Mobile Service

Section I. Retransmission at the Request of the Sender

2129 § 1. Stations of the mobile service must, if the sender so requests, serve as intermediaries for the exchange of radiotelegrams originating in or destined for other stations of the mobile service; the number of intermediary stations of the mobile service, is, however, limited to two.

2130 § 2. Radiotelegrams forwarded as described in **2129** above must bear, before the address, the paid service indication = RM = (retransmission).

2131 § 3. (MOD) The transit charge, whether two intermediary stations are concerned or only one, is fixed uniformly at forty centimes (0 fr. 40) per word pure and simple, without the collection of a minimum charge. When two stations of the mobile service have participated this charge is divided equally between them.

Section II. Routine Retransmission

2132 § 4. (1) When a land station cannot reach the mobile station for which a radiotelegram is destined and no payment for retransmission of the radiotelegram has been deposited by the sender, the land station may, in order to forward the radiotelegram to its destination, have recourse to the help of another mobile station provided that the latter consents. The radiotelegram is then transmitted to this other mobile station. The help of the latter is given free of charge.

2133 (2) The same provision is also applicable to traffic from mobile stations to land stations, when necessary.

2134 (3) The station assisting in the free retransmission in accordance with the provisions of **2132** and **2133** must enter the service abbreviation QSP . . . (name of the mobile station) in the preamble of the radiotelegram.

2135 (4) In order that a radiotelegram thus forwarded may be considered as having reached its destination, the station which has made use of this indirect route must have obtained the regular acknowledgment of receipt, either direct or by an indirect route, from the mobile station for which the radiotelegram was destined or from the land station to which it was to be forwarded, as the case may be.

ARTICLE 10

Advice of non-delivery

2136 § 1. When, for any reason, a radiotelegram originating in a mobile station and destined for a place on land cannot be delivered to the addressee, an advice of non-delivery is addressed to the land station which received the radiotelegram. After checking the address, the land station forwards the advice, when possible, to the mobile station, if necessary, by way of another land station of the same country or of a neighbouring country, as far as existing conditions or special agreements permit.

2137 § 2. When a radiotelegram received at a mobile station cannot be delivered, that station so informs the office or mobile station of origin by a service advice. In the case of a radiotelegram originating on land, this service advice is sent, whenever possible, to the land station through which the radiotelegram passed or, if necessary, to another land station of the same country or of a neighbouring country, as far as existing conditions or special agreements permit.

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